BRITISH REGIONAL GEOLOGY
SOUTH-WEST ENGLAND
(*SECOND EDITION*)

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DEPARTMENT

OF

EXTRA-MURAL

STUDIES

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SOUTH-WEST ENGLAND

I. INTRODUCTION

Form, Structure and Scenery

THE South-west province embraces Cornwall, Devon and part of Somerset : it is bounded by the Atlantic, the Bristol Channel and the English Channel, while on the east the area is terminated by an artificial boundary joining Bridgwater with the Axe valley.

Generally the area consists of high moorlands which include the Devonian rocks of Exmoor and the Quantocks, the Upper Greensand ranges of Black Down and Broad Down with their westerly continuation the Haldon Hills, and the granite moors of Dartmoor, Bodmin Moor, St. Austell or Hensbarrow, Carnmenellis and the Land's End, with the outlying Scilly Islands.

The coast-line presents a long range of high cliffs to the Atlantic, but more gently sloping hills to the English Channel. Bogs, marshes and heathy moors cover wide tracts inland, but in South Devon and parts of Somerset good agricultural land lies on the red earth.

Igneous rocks forming dykes, sills, flows and bosses contribute by their hardness to the relief of the land, and most of the small capes and headlands are composed of some kind of volcanic or intrusive rock. The hard grits and sandstones of the Lower Devonian and of the Culm Measures resist denudation and rise above the shale lands as long hill-ranges in North Cornwall. The Staddon Grits of the St. Breock and the Denzell Downs, the Culm Sandstones of Boscastle, and the Upper Devonian of Otterham and Davidstow find their counterpart in North Devon, near Lynton, the Hangman Hills and on Exmoor.

Structurally, Cornwall and Devon consist of a huge compound trough or syncline, with east-west axis passing through Crediton, and flanked, on the north and south, by smaller folds of similar trend. Development of these structures promoted the invasion of the country rocks by the great granite masses, in Permo-Carboniferous times, and the arrangement of the masses was probably governed by the points of coincidence of the east-west structures with deeper folds of east-north-east, or Caledonian, trend. Each granite mass is situated centrally with respect to a dome structure in the sedimentary rocks.

At the base of the geological sequence lie the pre-Cambrian rocks of the Lizard and the Start and Bolt. Above this complex the Ordovician rocks are seen as overthrust and smashed masses. They are preserved at Manaccan, Veryan and Gorran Haven. Overlying these rocks the Lower Devonian divisions, consisting principally of grits, sandstones and conglomerates with some calcareous beds, curve from near the North Cliffs to St. Eval and eastwards to the south of Dartmoor and to Babba-combe and Start Bay.

Rocks of Middle and Upper Devonian age succeed the beds of grit and consist mainly of slates and mudstones with local reefs of limestone, the shaly development being characteristic of North Cornwall, while the coral and 'stromatoporoid' limestones become dominant between Plymouth and Torquay in South Devon. Conspicuous among these Middle and Upper Devonian beds are widespread submarine lava-flows which often present pillow forms (Pl. IV). They are associated with tuffs and extend along a nearly continuous strip of country between the north coast of Cornwall, where they form the towering cliffs of Pentire and Trevalga, eastwards around Bodmin Moor to beyond Tavistock : a second strip extends from the south of Bodmin Moor past Liskeard and Plymouth to Ashprington and Tor Bay. There seems to be a close relationship between these lavas and the limestones, for where one series dies out the other appears : it may be that volcanic vapours locally prevented the growth of coral reefs.

Northwards rocks of Carboniferous age succeed the Devonian slates, but the relationship is obscure and the junctions are often faulted. Grits, soft black shales, poor slates and a little ' culm,' a sooty, carbonaceous matter, constitute the bulk of the deposits ; locally, however, great outbursts of vulcanicity are represented by lava-flows, tuffs and ashes as at Brent Tor, while thick beds of radiolarian chert appear to be contemporaneous with the volcanic series. Some thin layers of black limestone characterized by the presence of such fossils as *Goniatites sphaericostriatus* and *Posidonia becheri* also occur. This group of rocks comprises the Lower Carboniferous of Cornwall and South Devon : it reappears in North Devon, near Barnstaple, and extends thence eastwards to Somerset. The greater part of central Devonshire is occupied by the grits and shales of the Upper Culm Measures which recur with monotonous regularity. Some compensation is afforded, however, by the magnificent exposures of normal folds and of overfolds in the long range of cliffs between Boscastle and Hartland Point and around Bideford Bay to Appledore (Pl. V B).

Northwards again the Devonian rocks emerge and form the greater part of North Devon, the Lower Devonian beds occupying a band about four miles wide, the Middle and Upper Devonian another rather narrower band with discontinuous beds of limestone in the middle of the series. The precipitous cliffs of North Devon and West Somerset reveal sections of all these beds.

Earth-movements affected the region during two principal periods. The earlier movements brought about folding along axes directed N.E. and S.W. and pre-Devonian rocks retain the effects of these movements. Similar lines of folding affected wide regions in North-west Europe and are well seen in Scotland ; for this reason the direction of folding has been termed ' Caledonian.' If the movements ceased in early Palaeozoic times the folds appear to have controlled later emission of igneous rocks, for the granite-masses and the elvan dykes are distributed along a similar trend-line, while the mineralized fissures of West Cornwall pursue the same direction.

Rocks of Devonian and Carboniferous age were next deposited ; some in circumstances of quiet subsidence, others under stress with resultant vulcanicity, the whole area slowly sinking beneath the ocean on the south

but rising to shore levels in the north. Towards the close of the Carboniferous period, however, great stresses again disturbed the whole district : rocks were folded along east and west lines by pressures acting at right angles to this direction and locally with sufficient force to overfold and even to overthrust lower upon higher parts. Folds of similar direction affect Brittany and have therefore been termed ' Armorican ' from the ancient name for North-west France.

Towards the end of these disturbances the granite bosses entered into the domes and metamorphosed them, while volcanic activity on a minor scale broke out in the Permian period.

Apart from tilting and marine erosion the whole area seems to have lain quiescent since the New Red rocks were formed under desert conditions. Great screes of rock then gathered at the hill bases to form breccias and breccio-conglomerates, while the marls and sandstones were rapidly laid down in fresh water. It is to these rocks that the red earths of Devon are due.

At some parts of the Jurassic period the area was tilted eastwards and in later Cretaceous times cherty sandstones were deposited upon the upturned edges of earlier strata. These were in turn buried under the Chalk sea, while Tertiary gravels, partly of fluviatile origin, next covered the Cretaceous deposits.

Marine erosion was operative in late Tertiary times and, although deposits assignable to these periods are poorly developed, peneplains or plains of marine erosion have truncated wide areas of older rock and give rise to the present upland flats at 1,000 ft. and 750 ft. respectively. Lake deposits of pipe-clay and lignite are preserved at one or two localities, their age being probably Oligocene. The sea next cut a wide, gently shelving plain which has since been raised to a height of 430 ft. above O.D. and forms one of the characteristics of the coastal topography. Emergence was rapid and led to enhanced erosive powers of the rivers, and as a result the present streams follow curving courses in deep ravines studded with crags of bare rock.

Another marine platform, the Raised Beach, was cut during an early part of the Glacial period, the rock platform and its overlying beach being preserved at numerous places.

This elevation led to further deepening of the valleys to a total of over 100 ft. and has important effects upon engineering schemes, for owing to later subsidence these ancient valleys are infilled with clay and peat and form unstable foundations for bridges and embankments. Forests grew upon the subsiding valleys and their carbonized remains are often swept bare by storms removing the overlying sea-sand.

It is, however, to the granite and its emanations that Cornwall owes its great mineral wealth ; for the ores of tin, copper, tungsten, lead and zinc as well as the kaolinized tracts of the granite masses have alike resulted from the activity of these vapours and solutions.

History of Research

Among the early geological observers the name of William Borlase ranks first. In his ' Natural History of Cornwall ' published in 1758, he gives a good general account of the rocks and minerals of the county and

his acute powers as an observer are shown by his noting the occurrence of the bed of pebbles below the (Pliocene) deposits at St. Agnes Beacon. His ' Natural History ' possesses more than a mere historical interest.

Of more importance to the mining student is Pryce's ' Mineralogia Cornubiensis ' published in 1778. In the beginning of the 19th century the ' Transactions of the Royal Geological Society of Cornwall ' appeared, and among many annual volumes of interest two in particular stand out as classics from the mining point of view, the first being W. Jory Henwood's treatise ' On the Metalliferous Deposits of Cornwall and Devon ' published as Volume 5 of the Transactions, and the other, the Volume for 1912, by J. H. Collins on ' The West of England Mining Region.'

Conybeare was one of the earliest observers to classify the rocks of Cornwall and Devon, in 1814 and in 1823.

The official survey of Cornwall and Devon was some of the first work undertaken by the newly initiated Geological Survey. De la Beche was appointed the first Director of that institution, a fact commented on by Sir Charles Lyell in his presidential address to the Geological Society of London in 1836. Two years before, 1834, Greenough stated that De la Beche acting under the direction of the Board of Ordnance had produced a geological map of the County of Devon, and in 1835 he stated that of the eight sheets of Devon and Somerset on which De la Beche was engaged four were published, three others complete and the eighth nearly complete, while the explanatory memoir was to be published before the next anniversary of the Society.

In 1836 Sedgwick and Murchison commenced researches in Devonshire ; they separated the Carboniferous rocks (Culm Measures) from the general mass of deposits which De la Beche had described under the term ' Grauwacke,' while in 1839 they showed that much of the grauwacke formed a group between the Silurian and the Carboniferous, and the Devonian System was thus introduced. This conclusion resulted to a great extent from the researches of Godwin-Austen and from Lonsdale's conclusions as to the age of the limestones of Devon.

In 1839 De la Beche published his classical ' Report on the Geology of Cornwall, Devon and West Somerset,' but the term Devonian had not by then been introduced. In 1846 (' Essays,' *Mem. Geol. Surv.*, vol. i, p. 50) he stated ' in Cornwall and Devon there may be equivalents both of the Carboniferous limestone above and of the higher parts of the Silurian beneath also included in this system.'

In his report he gives credit to Mr. Henry McLauchlan and Mr. Henry Still, Ordnance Surveyors, for their able assistance in laying down the mineral veins, ranges of elvan and granite margins and for communicating to the Survey ' a mass of important geological facts.' Dr. Pattison of Launceston and the Rev. R. Hennah had helped with the collection of fossils, while the Rev. David Williams and Mr. Weaver indicated some of the main stratigraphical divisions among the older rocks.

De la Beche must also be credited with the conception and establishment of the Museum of Economic Geology which was opened in 1841 in Craig's Court, Charing Cross. The collections were transferred in 1851 to the Museum of Practical Geology in Jermyn Street. He also established the Mining Record Office, which was placed under the charge of T. B. Jordan and afterwards under Robert Hunt.

By 1840 De la Beche had issued a revised edition of the maps of Cornwall and Devon whereon he adopted divisions of the strata similar to those made by Sedgwick and Murchison as to the order of sequence, applying provisionally to the Culm rocks the term ' Carbonaceous ' series and to the Devon and Cornish slates the name ' Grauwacke.'

Sedgwick went to some pains to explain why it was that he and Murchison had not established the Devonian System in 1836 when they determined the great Culm trough of North Devon to be Carboniferous. His words are : ' we sent a good series of the fossils of Petherwin and Barnstaple groups to London. They were examined and named and every species was called Silurian . . . on re-examining the fossils in 1838 it turned out that all the species of the Barnstaple group had been wrongly named ; and that so far from being Silurian, the only doubt respecting them was whether they might not be called Carboniferous rather than Devonian.'

Geological research work was carried on between the years 1855 and 1873 by W. Pengelley and A. Champernowne in South Devon, while H. B. Holl studied the older rocks of the same area. They largely followed the work of Godwin-Austen, who in 1842 combined four of his previous papers into a connected description entitled ' On the Geology of the South-east of Devon ' ; this paper may be regarded as the foundation on which all subsequent work in the area was built. The fossil fish of the Polperro and Looe Beds were studied by C. W. Peach and the Rev. David Williams and as a result of their work the true stratigraphical position of the Dartmouth Slates was determined as Lower Devonian.

In later years much work was done by R. N. Worth, Howard Fox and Upfield Green, while the petrography and chemistry of the igneous rocks and mineral veins received exhaustive treatment by John Arthur Phillips.

The official revision of De la Beche's maps was commenced by W. A. E. Ussher in 1870 in the Wellington district. He gradually worked westward and in 1873 had reached Exeter and by 1875 the area around Torquay, where his associates were H. B. Woodward and Clement Reid. Ussher pressed forward through the Bolt and Start country and by Ivybridge and Modbury to Plymouth and St. Austell. He thus surveyed a very large part of South Devon and Cornwall, and by his knowledge of the Devonian of Belgium and Western Germany was able correctly to correlate the divisions of the Devonian system of the several areas.

South Cornwall was resurveyed by J. B. Hill, who divided the killas of the Falmouth district into several lithological types and assigned to them an early Palaeozoic age. J. B. Wilkinson and E. E. L. Dixon co-operated with him in Western Cornwall along with Clement Reid while D. A. MacAlister was responsible for the mineral survey.

Petrology of Cornish and Devonian rocks, as noted above, was dealt with by Phillips and also by Rutley and Allport, but Bonney was the first to attack the problem of the Lizard rocks by the methods of modern petrography (1877). His work and inferences raised a controversy in which Collins, Fox, McMahon and Teall took part. Somervail and Harford Lowe also contributed papers, Lowe settling the age of the granulitic gneisses. The study of the foliation of the Lizard rocks was advanced by Bonney, Teall and McMahon. Bonney and McMahon

ascribed this process to injection foliation in a viscous rock, whereas Teall appealed to dynamic metamorphism. It remained for Sir J. S. Flett to contribute the satisfactory explanation that the structures can only be brought about by means of both the agencies mentioned acting concurrently. Flett also described the petrography of the mineral veins, the processes of kaolinization and allied changes, the granites and their metamorphic aureoles and the greenstones and spilites. G. Barrow and H. Dewey contributed to the descriptions of these rocks, and with C. Reid, J. B. Scrivenor and R. L. Sherlock mapped a wide area of North Cornwall and West Devon.

The series of memoirs on Mineral Resources in so far as they relate to Cornwall and Devon is given on p. 73. All the information on the Metalliferous Mining region of South-West England has been collated by H. G. Dines and recently published in an exhaustive memoir. Torquay has been revised in recent years by W. Lloyd with the assistance of C. P. Chatwin and W. G. Shannon.

II. ROCKS OF PRE-DEVONIAN AGE

(1) THE LIZARD

THE Lizard peninsula when viewed from a distance presents the appearance of a platform (Frontispiece) lying two to three hundred feet above sea-level, the average height being 290 ft. All the streams flow in valleys cut in this platform, while cliffs, often bold, terminate the platform seawards. Many observers have studied this difficult district, among whom the names of Bonney, McMahon, Teall and Lowe may be mentioned, but it is to Sir John Flett that the most modern researches are due.[1]

The district is divisible naturally into a southern part with metamorphic rocks of the Lizard Series and a northern composed of intensely sheared sedimentary and igneous rocks. A zone of faults separates the two parts. The Lizard Series includes the following rocks :—

> Granite and granite gneiss
> Dolerite and epidiorite dykes
> Gabbro and flaser gabbro (with troctolite)
> Serpentine (bastite, tremolite and dunite)
> Man o' War Gneiss
> Hornblende schist
> Mica schist, granulite and green schist

The oldest rocks are the Old Lizard Head Series, which comprises mica schists, green schists and granulites.

The Mica Schists are exposed at Old Lizard Head (Pl. II A) ; originally these were marine muds and shales and were interbedded with sand that now constitutes the granulites. They were metamorphosed by the gneiss of the Man o' War rocks and subsequently by the serpentine. They show both contact alteration by the development of andalusite and sillimanite and also folding or regional metamorphism. Associated with these sediments are beds of volcanic ashes which also have suffered metamorphism and are highly schistose (Green Schists).

The distribution of these schists is indicated on Fig. 1. In addition to their occurrence west of Lizard Point they cover extensive areas between Porthallow and Porthoustock.

Next follow the Hornblende Schists (Landewednack Schists) of the Lizard Point and of the tract between Mullion Cove and Porthallow. Normally they are dark green rocks often striped with bands of grey felspar or yellow epidote and may be considered as a group of basic intrusive sheets and lavas completely metamorphosed.

The large intrusive masses of serpentine and gabbro have risen through these schists, and with the rest of the metamorphic rocks are of igneous origin. Probably no great time was required for the injection of the

[1] For papers see List of Maps and Publications on pp. 68-73.

whole complex : it includes hornblende schist, serpentine, gabbro, dolerite, epidiorite and several kinds of gneiss.

A small area near Treleague, St. Keverne, is underlain by quartzite, which shows its original pebbly structure, and by grey phyllites associated with it.   These rocks are probably later than the Lizard schists, for they are distinct from them in their lower state of metamorphism.

The serpentine mass (Fig. 1) has a nearly round outline although its actual boundaries are not seen where the sea has eroded the girdle of
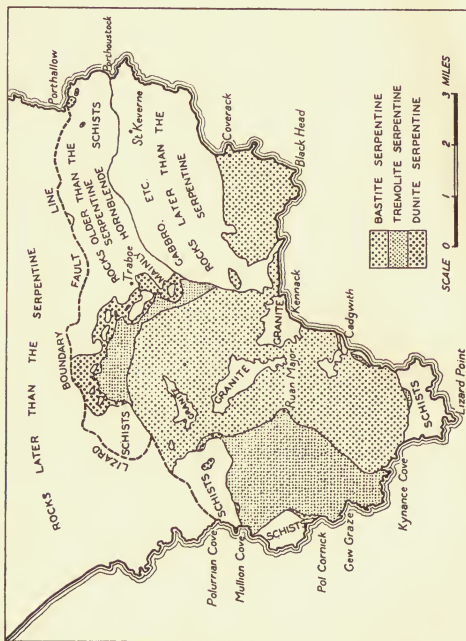
FIG. 1.—Sketch-map of the geology of the Lizard peninsula.

schists that once encircled it. The mass consists of zones or belts that have a rudely concentric arrangement.   The central and largest portion consists of coarsely crystalline rock with large shining plates of enstatite or bastite (bastite serpentine).   The rock forms much of Goonhilly Downs, the shores of Kennack and Ruan Minor and Black Head. Traced outwards it merges into a streaky, banded, rather fissile rock, fine-grained and locally schistose (tremolite serpentine). Large bastite plates are scarce, but often light green spots of tremolite are visible.   It is

common along the north margin of the serpentine, about Traboe, extends from Mullion over Predannack Downs to Kynance (Plate I), and is found also at the Lizard and Cadgwith.

A third type of serpentine (dunite serpentine) is found near the junction with the hornblende schist; its outcrop is shown on Fig. 1 by large black spots. It is compact with a lustrous hollow fracture like a piece of dark green glass and is often traversed by many fine satiny veins. This zoned structure is evidence that the serpentine is an intrusive rock that welled up and forced outwards the surrounding schists. The fine
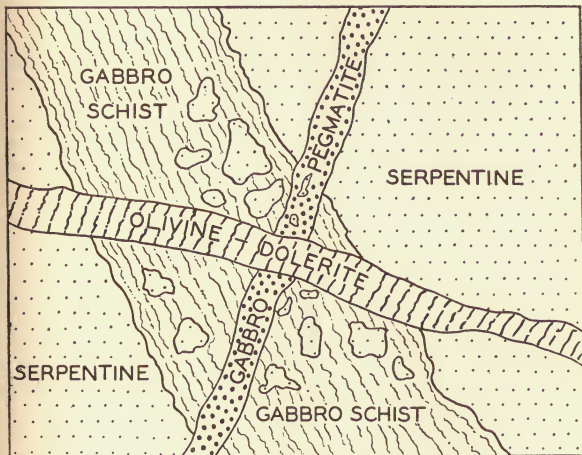
Fig. 2.—*Section at Coverack Cove.*

Gabbro broke through the serpentine and caught up boulders of serpentine in the process: contemporary movements sheared the gabbro into a schistose condition. Dykes of gabbro pegmatite next broke through the earlier formed rocks, while these were succeeded by the emission of dykes composed of olivine dolerite passing into more acid rocks. The section is important as it is an epitome of the igneous history of the Lizard district. It is easily accessible and well exposed and merits the closest examination.

flinty serpentine was the earliest and the coarse bastite the last part of the intrusion. Kynance Cove (Plate I), one of the most beautiful scenes in Cornwall with its varied rock forms and colours, shows the effects of erosion upon these different kinds of serpentine.

An extensive mass of gabbro covers the area south of St. Keverne, indicated on Fig. 1 by the words 'rocks later than the serpentine,' while innumerable dykes of gabbro are to be found in the serpentine near Coverack (Fig. 2) and Kennack. The gabbro is a coarse aggregate of

grey plagioclase felspar, greenish augite and hornblende. Flaser structure is often developed, as at Carrick Luz.

Troctolite, a variety of gabbro, consisting of olivine and plagioclase felspar occurs on the shore at and south of Coverack. It is intrusive into the serpentine and is itself cut by veins of gabbro.

After the gabbro had cooled a renewed injection of basic material took the form of narrow black dykes that filled vertical fissures in the gabbro and the serpentine. Some are fresh olivine dolerites ; others are much decomposed, while many have been converted by pressure into epidiorites and hornblende schists. The sequence of these igneous rocks is revealed at Coverack, where the section illustrated in Fig. 2 is exposed.

As the period of injection of the black dykes was drawing to a close an acid magma appeared—the Kennack Gneisses. At first it formed only thin streams of reddish material in the black dykes : next imperfectly mixed material, partly acid, partly basic, gave rise to banded rocks. Finally, a red granite was intruded and veined the banded rock, and ultimately in sufficient quantity to form laccolitic masses of pink and grey gneiss in the serpentine, three of which are shown on Fig. 1 north-west of Kennack. This emission terminated the eruptive period.

(2) MENEAGE, FALMOUTH AND VERYAN AREAS

The Lizard complex is faulted against a series of sediments, of unknown age, extending from Polurrian Cove in a general E.N.E. direction to the coast at Porthallow (Fig. 3). Where the two series meet, the members of the northern group are seen to be completely sheared to such a degree that original structures are obliterated and numerous elongated lenses of hard rock lie in strands of shaly matter, and this structure is repeated on a microscopic scale. Among the larger lenses hard grey quartzite forms an important constituent and as they weather white they form conspicuous masses in the cliff faces, on the foreshore and in the fields. No order of succession has been established with certainty, but J. B. Hill was led to infer on field-evidence that in descending sequence the rocks form the following series :—

> Veryan Series
> Portscatho Series
> Falmouth Series
> Mylor Series

The Veryan rocks, both sedimentary and igneous, show widespread brecciation and form a series of crush-breccias. The earth-movements to which this breaking up was due terminated before the Devonian beds were laid down. Between Mullion Island and Porthallow numerous outcrops of pillow lava and tuff are found with the Veryan Series and all are much shattered and brecciated but not greatly sheared.

At Carne and other localities near Veryan and at Gorran Haven some quartzites contain fossils which according to the Memoir on Mevagissey include the following species : *Orthis calligramma, Orthis porcata ?, Calymene tristani* Brongn., *Calymene cambrensis* Salt., *Phacops mimus* Salt., *Phacops incertus ?* Desl., *Asaphus powisi ?* Murch., *Cheirurus sedgwicki*

PLATE 1

(A.570)

KYNANCE COVE FROM THE NORTH-WEST
[For explanation, *see* p. v.]

(A.553)

A.—OLD LIZARD HEAD; CRUMPLED SCHISTS AND GRANULITE
[For explanation, *see* p. v.]

(A.590)

B.—COMPASS COVE, ST. KEVERNE: DYKES OF GABBRO IN SERPENTINE
[For explanation, *see* p. v.]

(*A.*5970)

A.—MORTE POINTE, MORTHOE: THE MORTE SLATES
[For explanation, *see* p. v.]

(*A* 5992)

B.—COMBE MARTIN BAY WITH THE LITTLE HANGMAN
[For explanation, *see* p. v.]

(*A*.431)

A.—Pentire Head, St. Minver.　Pillow lava
[For explanation, *see* p. v.]
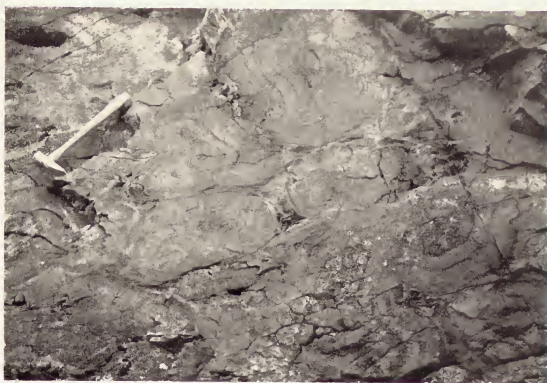
(*A*.458)

B.—Section of pillow lava at Pentire Head
[For explanation, *see* p. v.]
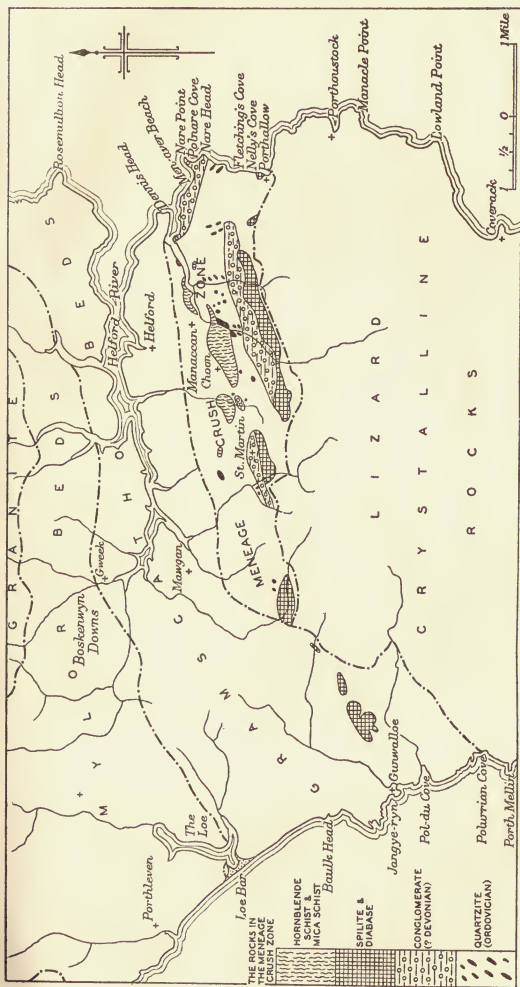
Fig. 3.—Sketch-map of the geology of the Meneage district.

M'Coy. These are probably of Llanvirn or of Llandeilo age. There is therefore evidence of the existence of Ordovician rocks in South-east Cornwall. But the beds are discontinuous and lenses of dark blue limestone occur in the same cliffs at Porthluney Cove, and these contain among others the following forms : *Actinoceras baccatum* H. Woodw., *Barrandeoceras holtianum* (Blake), *Ptilodictya lanceolata* Lonsd., *Rhynchotreta cuneata* (Dalm.), *Amphicoelia striata* (Sow.). These fossils are possibly of Wenlock age. At Kiberick Cove, in addition to such lenticles, masses of gabbro and of serpentine are incorporated among the sediments, the whole assemblage forming an overthrust mass of material of different ages. This heterogeneous mass lies next below the almost unfossiliferous grits, sandstones and slates of the Mylor, Falmouth and Portscatho series, to which different ages have been suggested ranging from Cambrian to Upper Devonian ; while still less is known of the age of the ' Dodman phyllites.' Lithological similarity is insufficient for accurate correlation, but it is notable that the Falmouth variegated slates resemble the Lower Devonian rocks of Watergate Bay, although in the absence of fossils exact correlation is impossible. The distribution of these series of rocks is confined to the southerly parts of Cornwall and extends southwards of the Devonian outcrop from north of Porth Towan to north of Mevagissey (Fig. 4), covering the main mining regions of Camborne, Redruth and the Land's End.

Members of these series pass by insensible gradations the one into the other and there is uncertainty as to which member is the oldest.

The Mylor and the Portscatho rocks closely resemble each other, and it has been suggested that they are the same beds folded into a syncline. They extend northwards between Gerran's Bay and Porth Towan, and southwards into the Mount's Bay region.

The Mylor Series consists of blue argillaceous and fine-textured sandy rocks, some forms approaching quartzites. Their distinguishing feature is their banding, due to fine interlaminations of quartzose and argillaceous seams, or to different grades and colours of the argillaceous material itself. While this banding is characteristic of the Mylor beds, it is not confined to them—in the higher divisions, however, it is seldom seen.

Both argillaceous and fine sand beds comprise the Falmouth Series, their marked characteristic being their proneness to decomposition and their bright buff, brown and green hues. Purple and green slates locally form a conspicuous zone, and blue slates, similar to the Mylor Slates, are interbedded.

The Portscatho Series consists of blue and grey clay slates, sandy silts and strong grits. Much clastic mica remains, but felspar is only a subordinate constituent in rocks that are principally quartzose. During the official survey Hill and Pringle collected plant remains at several localities and assigned the rocks in which they were found to the Devonian.

In recent years plant remains found by Dr. L. Hendriks in the Falmouth and the Portscatho rocks have been examined by Prof. W. H. Lang, who recognizes among them traces of the woody structure ' *Dadoxylon* ' which hitherto has not been found in rocks earlier than Upper Devonian, although Prof. Seward in ' Plant Life through the Ages,' edit. I, 1931, p. 126, warns us that ' we cannot, however, confidently assert that no trees with stems of Dadoxylon type existed before the middle of the

Devonian period.' Sir John Flett has accordingly grouped together the Falmouth and the Portscatho Series with the Grampound and Ladock Beds, calling them the Gramscatho Beds, and tentatively has placed them in the Middle Devonian. Messrs. Upfield Green and Evans considered that the Mylor and Portscatho Beds correspond to the ' Schistes et Quartzites de Plougastel ' of Brittany and the ' Schistes de Mondrepuits ' of Belgium and thought that they represent passage beds between the Silurian and the Devonian.

In the Meneage Crush Zone (Fig. 3) all the available fossils have been re-examined by Dr. C. J. Stubblefield (1939) : he concludes (p. 67) that there is not direct evidence for the presence of Ordovician strata, but ' fossiliferous Devonian strata are present at two localities. . . . The Lower Devonian grey-green siltstone at Mudgeon appears to be Lower Coblenzian (Emsian), the black calcareous shale at Carn (near Manaccan) is probably also Lower Devonian. Both occurrences are likely to be newer than Gedinnian, the subdivision of the Lower Devonian to which the Gramscatho Beds (as now interpreted) and Mylor Beds were referred years ago by Green and Sherborn (1912, p. 560).'

Large masses of igneous rock, mostly of intrusive origin, and locally called greenstone, occur in the Mylor sediments north-west and north-east of the Carnmenellis granite mass, and similar masses lie in the Veryan rocks around Veryan Bay. A number of wide sills in the Mylor beds extends south-westwards between Camborne and St. Erth, while masses of epidiorite flank the granite by St. Ives, Zennor, Botallack, near Penzance, and extend thence along the shores of Mount's Bay to Cudden Point.

The more massive greenstones, whether they were originally intrusive sheets or interbedded lavas, have in many cases suffered little from the deforming movements by which the killas has been so greatly disturbed, and even where parts of a greenstone mass are sheared there are usually other parts which have escaped crushing and have served as phacoids, around which the adjacent rock was compelled to flow. Hence it is often possible to make out the original structure and to refer it to certain of the established categories.

Ophitic structure is far less general than might have been expected in large intrusive sheets. The felspars yield broad, squarish, or rectangular sections. Their twinning is usually complex, and when they are fresh it is sometimes possible to establish that they belong to albite-oligoclase and oligoclase, but more basic varieties also occur. Augite is represented by uralite and chlorite enveloping the felspars. Fine granular yellow epidote is mixed with the chlorite. Networks of ilmenite and prisms of apatite are frequent.

Another group of sheared dolerite sills is of finer grain and shows small lath-shaped felspars often with a parallel arrangement. Between the felspars there is chlorite and finely fibrous actinolite, grains of iron ore, and some epidote. These rocks appear to have been contemporaneous lavas. Allied to them are rocks with felspar-laths in radiate bundles embedded in secondary chlorite, actinolite and leucoxene.

Where these greenstones lie in contact with the granite they have been metamorphosed to hornfels, and although they present a great variety of structures, and differ considerably in the relative abundance of their components, they consist only of a few minerals.

Hornblende is very common and in the extreme stages of contact-alteration it is always of a rather pale brown or brownish-green colour. It may form fairly large crystals or it is entirely acicular with needles so fine that it is only by analogy that they are referred to hornblende. Less abundant, though plentiful, is a colourless or pale green augite in small, ill-shaped crystals which form in some rocks bands or folia without any other minerals. Dark green hornblende often partly surrounds the augite.

Strongly pleochroic brown biotite is a common mineral. Felspar forms a groundmass in which the other minerals lie. Where determinable it belongs to oligoclase. Iron ores, minute granules of sphene and small crystals of apatite are usually present.

The greenstones locally show modifications due to the effects of fluoric and boric vapours which passed along fissures or joint planes. The lime of the igneous rock and the lining of its fissures was converted into axinite (boro-silicate of lime and alumina) and fluorspar. Other characteristic minerals are epidote, garnet and iron ores. Similar types of igneous rocks extend upwards through the Devonian into the Culm Measures.

(3) The Start and the Bolt districts

In South Devon between Start Point and Bolt Tail schistose rocks lie in contact with Lower Devonian slates : the junction appears to be a series of faults (Fig. 4).

These schistose rocks comprise three main types : (1) green schists or hornblende and chlorite schists, (2) mica schists and (3) quartz schists, and there are also some red rocks that appear to be altered tuffs and ashes.

(1) The Green Schists form on the east of the promontory two bands which run together at Salcombe and extend thence as one to the west coast by Bolt Tail. There are several kinds of rock of a general green colour, but yellowish-green and deep blue-green are the characteristic tints : where they are in contact with the Devonian slates red and brown stains due to hydrous iron oxide mask the green tints. Schistosity is prevalent although locally massive forms are present. Colour bands in the schists simulate bedding and the effect is accentuated by weathering out of quartz veins between the folia. Nodules of albite felspar and of epidote up to six inches across are fairly common ; some may be amygdules from volcanic rock.

These schists are divisible into : (1 A) chlorite-epidote-albite schists, and (1 B) hornblende-epidote-albite schists, the two types grading one into the other, the differences being the result of dynamic metamorphism that they have respectively suffered. All of them appear to have been either lavas or sills of basic rock.

Schists of a composite origin lie at the upper and the lower horizons of the green schists. These consist of chlorite, epidote, albite, calcite, muscovite, quartz and hornblende and sometimes garnet and other minerals. These rocks were probably originally tuffs and basic ashes.

(2) The Mica Schists and (3) the Quartz Mica Schists form a uniform group, in which schistosity is well developed, and constitute the greater
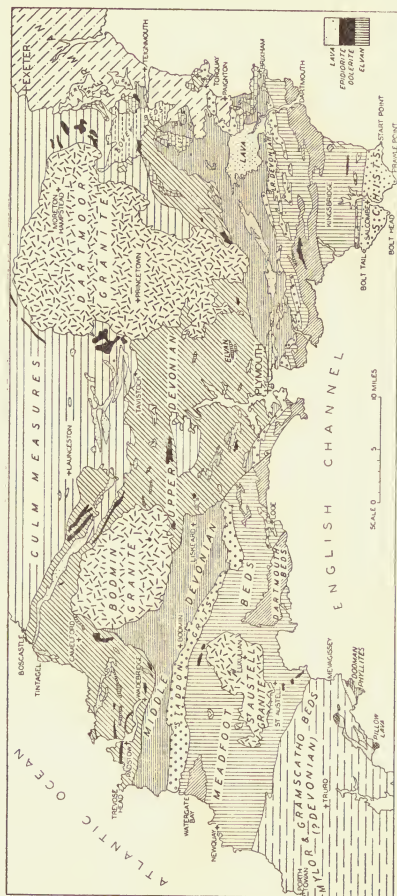
Fig. 4.—*Sketch-map of the geology of South Devon and part of Cornwall.*

part of the metamorphic area between the two bands of green schists lying east of Salcombe Harbour, but westward separated into two tracts by the belt of green schists.

Almost everywhere they have been permeated by solutions of quartz, and quartz veins and quartz-albite veins up to a foot thick are common.

The Mica Schists and the Green Schists are interbanded and obviously closely related in time the one to the other.

These schists are built up of muscovite and quartz, but chlorite and albite are important constituents, while several accessory minerals are normally present including tourmaline, epidote, rutile and ilmenite.

It is unknown when these schists originated : they may be altered Lower Devonian rocks, but it is far more probable that they are remnants of an early Palaeozoic or even pre-Palaeozoic land-mass that has been brought into contact with the Lower Devonian beds by faults.

Their metamorphic state more closely resembles that brought about by earth-movement of the low grade dynamic type than that due to contact with molten igneous rocks such as the granite masses.

III. DEVONIAN ROCKS

(1) LOWER DEVONIAN

(a) CORNWALL AND SOUTH DEVON

THE Lower Devonian rocks outcrop over that portion of South Cornwall not occupied with the rocks already described, in parts of North and of East Cornwall and in South Devon, and they also form a wide band along the coast of West Somerset and North Devon. In South Devon and in Cornwall they have been divided mainly on lithological characters into the following ascending sequence : the Dartmouth Beds, the Meadfoot Beds and the Staddon Grits (Fig. 4).

A local group of conglomerate beds in sandstone (Grampound, Ladock and Manaccan Beds) are probably of Lower Devonian Age.

From Dartmouth, South Devon, to the east of St. Austell Moor their outcrop runs nearly east and west, but an anticline repeats the beds north of the Start and the Bolt. The beds are folded in another anticline around St. Austell Moor and extend to Watergate Bay, north of Newquay, to the sea. They have been shifted north-west by a large fault between Plymouth and Looe.

The Dartmouth Beds lie at the base of the Lower Devonian Series and are characterized by their variegated colours, ranging from purple to green, and by their general argillaceous composition. Locally remains of fish have been preserved in them including *Pteraspis* [*Steganodictyum*] *cornubica* (M'Coy), which fish must have attained a considerable size. Remains of a Cephalaspid form called by M'Coy *Steganodictyum carteri* are common, while spines assignable with reserve to the Acanthodian genera *Climatius* and *Parexus* have been found at Watergate Bay.

The only definite marine invertebrate found is *Bellerophon trilobatus*, which, although common, is badly preserved.

No trace of volcanic activity has been recognized among these beds in Cornwall.

The Meadfoot Beds are a group of rocks consisting mainly of greyish slates with seams and thin beds of siliceous material, and also locally with beds of limestone, that has tentatively been called the middle division of the Lower Devonian and as the beds were first recognized at Meadfoot, near Torquay, the term Meadfoot Beds has been applied to the group. They pass upwards into similar rocks, but an increasing quantity of siliceous material leads to the formation of beds of grit and quartzite and these upper beds, well exposed at the Staddon Heights, Plymouth, are termed the Staddon Grits. These grits form the conspicuous downs, traversing Cornwall from east to west north of the St. Austell granite mass, which terminate in the magnificent cliffs near Bedruthan, North Cornwall. Marine fossils have been found in the Meadfoot Beds including a species of a fish, *Pteraspis*. This fauna includes *Rhynchonella pengelliana*, *Spirifer subcuspidatus* and other forms, *Orthis*, *Stropheodonta*

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gigas and *S. murchisoni, Bellerophon ? trilobatus, Pleurotomaria, Pleuro-*
dictyum problematicum and trilobites (Pl. XII). The most closely related
assemblages appear to be those of the Siegenian and Emsian of the Rhine.
The rocks form the picturesque scenery of Porth Island, Newquay
Headland, Fistral Bay and the Pentires.

The Manaccan Series includes coarse breccio-conglomerate, sandstone
and clay-slate, often calcareous. Material derived from the Portscatho and
the Veryan rocks, also fragments of granite and gneiss, schist, quartzite,
pillow lava and chert can all be found, and fragments of the conglomerate
form pebbles in the conglomerate. Locally the conglomerate is so badly
sheared that but few large pieces remain intact and its recognition thereby
becomes difficult. The sections of the Manaccan Beds in Gillan Creek
resemble in texture the Permian breccio-conglomerates of South Devon
but are seldom so coarse grained. It has been correlated with a con-
glomerate at the base of the Grampound and Ladock Beds. Although
most observers agree as to the Lower Devonian age of the Grampound
Beds, and locally this age is proved by the occurrence of *Proschizophoria*
cf. *personata*, there has been a great difference of opinion as to what part
of the Lower Devonian the group belongs : some observers have assigned
it to the Staddon Grits, others to the base of the Meadfoot Beds, while
a third suggestion is that it consists of sheared parts of both these divisions.
Although on fossil-evidence it is comparable with the Siegener Grauwacke,
there is the further possibility that it is still later. Traced westwards
from the south coast the constituents of the Grampound Grits diminish
in size until in mid-Cornwall they are comprised only of fine grit beds.
The source of the material therefore lay to the south-east—the area
whence the Ordovician and Silurian shear-lenticles came. Recently
some of these beds have been grouped by Sir John Flett with the Portscatho
and termed ' Gramscatho Beds.'

The Ladock Beds were assigned to the Staddon Grits on account of
the similar lithology of the grit phase to the Staddon Grits of the Denzell
Downs — Staddon Heights range of North Cornwall ; the assumed
structure being a wide anticline with a steeper dip of its northern
limb.

The Lower Devonian in common with other rocks of Cornwall and
Devon were thrown by Armorican movements from the south-east into
innumerable folds and overfolds and were frequently thrust, and many
exposures reveal the structure of the rocks as a series of closely packed
isoclines. Most of the clay beds have suffered cleavage, and, in many,
a secondary ' thrust ' or ' strain-slip ' cleavage buckles up the earlier
cleavage. Bedding is always obscured by these mechanical movements,
but locally it is recognizable by changes of lithology and colour, and by
thin lava-beds and tuffs. Estimates of the thickness of the beds are likely
to be inexact and exaggerated on account of repetitions of the sequences
by thrusts and faults. Fossils are rare and where present are often in-
determinable, but locally are in a sufficiently good state for their age to be
approximately indicated.

Lithological sequences or repetitions of shales, sandstones, grits and
thin limestones undoubtedly occurred throughout Devonian times, and
the beds are frequently indistinguishable even when belonging to widely
different ages. To cite but one instance, which even misled Sir Henry

De la Beche ; the variegated slates of Watergate Bay belonging to the lowest division of the Lower Devonian were correlated by him on lithological grounds with the variegated slates of Upper Devonian age of the St. Minver district, a correlation which led to a wrong inference as to the structure of North Cornwall.

Thermal metamorphism has further obscured the criteria by means of which true correlation could be effected, but such metamorphism is not in all instances wholly disadvantageous, for where the calcareous slates of the Meadfoot division have been metamorphosed they form intensely hard flint hornfelses which resist denudation and so form conspicuous hill-ridges that follow the strike of the beds and can thus readily be mapped. An illustrative example occurs between the granite masses of Bodmin Moor and St. Austell, especially in the parishes of Withiel and Wenn.

(b) NORTH DEVON

North of the great central syncline of Devon the marine Devonian rocks emerge from beneath the Culm Measures (Fig. 5). They form the magnificent ranges of cliffs along the coast between Morte and Minehead and crop out again in the Quantock Hills, but are absent between the Silurian and Carboniferous formations of the Mendip Hills.

They have been divided into Lower, Middle and Upper Devonian and into the following minor subdivisions :—

Upper Devonian	⎧ Pilton Beds
	⎨ Baggy and Marwood Beds
	⎩ Pickwell Down Sandstones
?	Morte Slates
Middle Devonian	Ilfracombe Beds
Lower Devonian	⎧ Hangman Grits
	⎨ Lynton Beds
	⎩ Foreland Grits

These subdivisions overlap the threefold grouping in part, the upper beds of the Hangman Grits being probably of Middle Devonian age, while the Ilfracombe Beds include Upper Devonian fossils in some of the higher limestones and shales.

The coast between Lynton and Minehead consists of an anticline with a N.W.–S.E. axis, and a similar axis trends through the Quantock Hills. The whole series is intensely plicated, compressed and cleaved, the southerly dips being generally those of isoclinal folds (Fig. 6).

The *Foreland Grits* consist of red and grey quartzose grits interbedded with reddish slates, usually unfossiliferous but with undetermined plant remains near Minehead, and some belonging to the genus *Psilophyton* at Porlock.

The *Lynton Beds* may include several horizons of the Lower Devonian. Blue-grey slates with some grit bands and partly decalcified calcareous beds are the normal development. Locally the beds are fossiliferous and have yielded among others *Spirifer primaevus, Spirifer hystericus*, both Siegenian forms, *Spirifer canaliferus*, ' *Orthis* ' *arcuata, Chonetes sordidus* and the corals *Pachypora cervicornis* and *Alveolites suborbicularis*. Some of these forms occur also in the Upper Devonian rocks.

The *Hangman Grits* resemble the Foreland Grits and form the north-west portion of the Quantock Hills and also the coast between Lynmouth and Hangman Point (Pl. III B). The lower beds consist of fine-grained
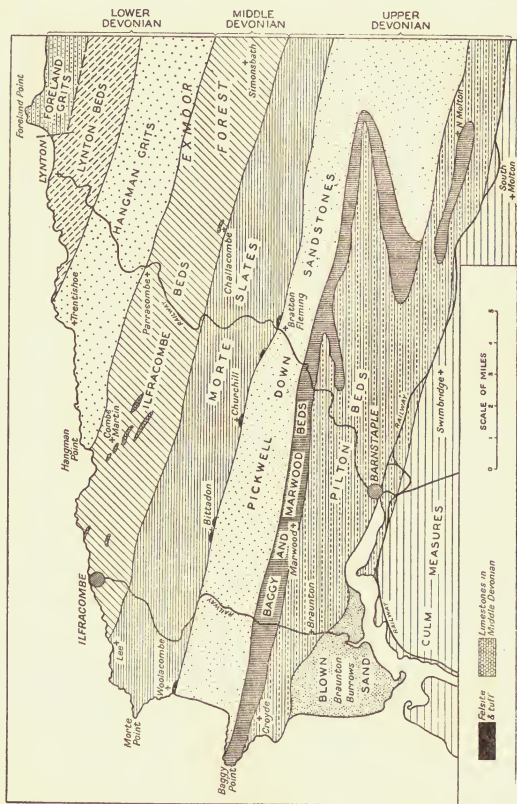
FIG. 5.—*Geological map of North Devon.*
(After J. G. Hamling.)

red sandstones and are unfossiliferous. They are succeeded by shaly and gritty deposits in which plants occur, while a fish scale of *Coccosteus* relates them to the Middle Devonian. *Calamites cannaeformis* found at the north end of the Quantocks is a Middle Old Red Sandstone plant.
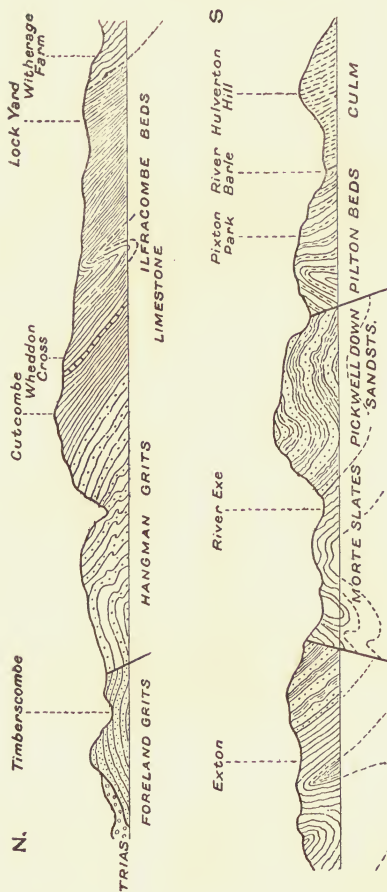
Fig. 6.—Section from Hulverton Hill, near Dulverton, to Wheddon Cross and Timberscombe. (After Champernowne and Ussher.)

(2) MIDDLE DEVONIAN

(a) CORNWALL AND SOUTH DEVON

Rocks of undoubted Middle Devonian age occur at Torquay, Brixham, Totnes and its neighbourhood and in the Plymouth area, but thence through Cornwall (Fig. 4) to the coast it has been found difficult to find true Middle Devonian fossils, the prevalent forms occurring also either in the Lower or in the Upper Devonian.

In South Devon a series of grey shaly slates and lenticular masses of limestone are highly fossiliferous : they are associated with and locally replaced by volcanic rocks, both spilitic lavas and stratified tuffs. The massive limestones disappear west of Plymouth, their representatives being thin lenticles in the shales. Near Torquay the limestones are underlain by grey shales with *Calceola sandalina* (Pl. XII), *Atrypa reticularis* and other Middle Devonian fossils.

Limestones occur at a lower and at a higher horizon. The lower beds are generally dark grey or black, and are well bedded. Crinoid ossicles form the bulk of the rock ; beds containing corals and stromatoporoids occur at intervals but are never more than 4 ft. thick. These beds are well developed around Dartmouth, Totnes and Torquay. Corals from them include species of *Heliolites*, *Pachypora* (Pl. XII) and ' *Cyathophyllum*.'

The higher limestones range up to 200 ft. in thickness ; they are grey or nearly white, pinkish or mottled grey and red. When polished they make beautiful ornamental marble. Generally they are massive and unstratified and are often built up of masses of stromatoporoids (*see* Pl. XII) some measuring 4 ft. across. Compound corals in broken lumps are not uncommon, *Pachypora cristata* and *Heliolites porosus* being characteristic.

These limestones pass upwards into beds containing a mixture of Middle (*Stringocephalus burtini*) and Upper Devonian species (*Hypothyridina cuboides*). This mélange may be due, however, to a slight non-sequence. On the north coast of Cornwall beds lying next above the Staddon Grits form the picturesque islets, sea-stacks and precipitous cliffs of Bedruthan. They consist of dark grey slate and locally are highly fossiliferous, but the fossils are not characteristic of the Middle Devonian, for many occur in Lower Devonian rocks elsewhere. One fossil, *Pteroconus mirus*, is particularly characteristic : it occurs on the coast through a considerable thickness of beds and has been found at inland localities. Numerous fish remains, including *Pteraspis* and *Climatius*, are locally common. Farther north, at Porthcothan, *Conularia complanata*, *Asteropyge sp.* and other forms occur as weathered-out pyritous casts : they also occur in the Upper Devonian, whereas rocks north of the Camel estuary associated with tuffs at Cant Hill contain Middle Devonian forms.

(b) NORTH DEVON

In North Devon (Fig. 5) the Middle Devonian beds include many bands of siliceous limestone, formerly classed as the Ilfracombe Beds, but since subdivided into a number of place-name groups. The basal beds contain marine fossils including *Cucullaea unilateralis* var. *angusta*,

and *Spathella munda*. The *Stringocephalus* limestones appear to overlie these beds and are well developed west of Little Hangman Hill (Pl. III B) where the species *Stringocephalus* cf. *burtini* is abundant. A series of shales and limestones with grits in their higher beds passes up into limestones and calcareous slates, the limestones containing the corals *Phacellophyllum caespitosum*, *Endophyllum bowerbanki* and *Pachypora cervicornis* (Pl. XII). Massive red unfossiliferous limestones follow, with slates and limestones above them yielding numerous poorly preserved fossils including *Heliophyllum helianthoides*, *Petraia*, *Pleurodictyum*, *Syringopora*, *Euomphalus circularis*, *Leptaena analoga* and other forms. Beds characterized by the presence of felted masses of fucoids occur in this series. The overlying shales and calcareous sandstones with *Fenestella* and *Spirifer verneuili* appear to belong to the Frasnian division of the Upper Devonian, while the lower beds may be compared with the Givetian of the Belgian Middle Devonian.

The Morte Slates appear to overlie the Ilfracombe Beds ; they consist of smooth and glossy sparsely fossiliferous slate with occasional calcareous nodules and sandy seams. They extend across North Devon into Somerset (Fig. 5 and Pl. III A), and have yielded fossils in both counties. Their exact age has long been and is still uncertain, but the assemblage of fossils on the whole indicates a Lower Devonian fauna, although the discovery in them of *Spirifer verneuili* may relate them to the Upper Devonian. Some of the species resemble Silurian forms, *e.g.* *Orthis rustica*, others Lower Devonian, such as *Stropheodonta taeniolata*, *S. explanata*, *Chonetes plebeius* and *C. sarcinulatus*.

(3) UPPER DEVONIAN

(a) CORNWALL AND SOUTH DEVON

The Upper Devonian rocks of Cornwall (Fig. 4) usually rest on a bed of tuff which can be traced westwards from Wadebridge to the coast. Around the Camel estuary a wide compound syncline brings in the Upper Devonian sequence. Faintly banded grey slates, with *Styliola* and *Tentaculites*, form the base ; they are succeeded by slates that are either black or grey with groups of goniatites that in Germany are termed the Büdesheim and the Nehdener faunas. In Daymer Bay, Portquin, Booby's Bay and Trevone Bay such slates contain pyritous casts of *Buchiola retrostriata*, *Tornoceras simplex*, *Cheiloceras*, *Allorisma concinna* and trilobites of several genera.

In St. Minver, St. Endellion, St. Kew and other parishes west of Bodmin Moor, all on the north side of the St. Minver syncline, a great development of spilitic pillow lava immediately succeeds these black slates, whereas thinner tuffs, ashes and limestones occur on the south. The strongly banded, alternate black and white, limestones and slates of the Marble Cliffs are at the spilite horizon and similar sharply folded beds of limestone are seen near Rock. The centre of the syncline is occupied by banded purple, green and ochreous soft slates with *Entomis serratostriata*, *Posidonia venusta*, *Phacopidella ductifrons* and other Famennian fossils. The sequence is therefore similar to the Rhenian Devonian where the Cypridinen Schiefer succeeds the Büdesheim Schiefer.

Near South Petherwin and Launceston greenish calcareous slates and

limestone are overlain by massive sandstone, calcareous sandy shales and blue slates which appear to be associated with the Famennian. They contain in additon to the fauna of the Cypridinen Schiefer the well-known *Clymenia* fauna, including *Clymenia laevigata, C. undulata, C. striata, Spirifer verneuili* and other forms. North of Petherwin, Launceston and Laneast there are inliers of green and dark grey slates, with *Phacops granulatus, Entomis serratostriata,* etc. Along the Tintagel coast (Fig. 7) these beds cannot be recognized, for metamorphism has so changed their character that the soft shales have become phyllites, while the pillow lavas are green schists. An upward sequence of lithological types, however, forms the most continuous and persistent series of Devonian rocks of South-west England, extending from Lewannick to Trevalga (Fig. 7). From below upwards it consists of (i) the Delabole Slates with the wide form of *Spirifer verneuili,* the so-called ' Delabole butterfly,' and fish remains resembling *Psammosteus* : (ii) the Woolgarden phyllites, soft sericitic and chloritic banded rocks speckled with chloritoid, ottrelite and chlorites, but unfossiliferous : (iii) the black siliceous hard slates of the Barras Nose Beds : (iv) a great thickness of sheared pillow lava and tuffs : (v) a second bed of hard black siliceous slates overlain by (vi) the Tredorn phyllites, grey-green, sericitic and chloritic phyllites with crystals of felspar developed on the cleavage planes, and often highly fossiliferous, *Spirifer verneuili* being abundant. Limestone occurs with the Barras Nose Beds, and some fossils comparable with *Hypothyridina cuboides* have been found in them.

These beds lie in an elongated anticline pitching north-west (Fig. 7). At its nose extensive overthrusts have repeated the sequence, the structure being exposed in plan and elevation in the Tintagel Cliffs (Figs. 8–9).

Inland the Upper Devonian rocks often yield fossils, but it is not till the South Devon coast near Torquay is reached that a good sequence can be established. In Saltern Cove the Famennian and Frasnian Beds with the Knollenkalk and Clymeniakalk occur in association with volcanic rocks. In this area Anniss has shown that the goniatite sequence described by Wedekind can be traced.

(*b*) NORTH DEVON

In North Devon (Fig. 5) the Upper Devonian period appears to have commenced with a volcanic episode, for a bed consisting of volcanic ash lies at a number of places at the base of one of the lower divisions—the Pickwell Down Beds—and thus corresponds with the occurrence in North Cornwall where vast submarine flows of lava were outpoured.

The Pickwell Down Beds consist of red, purple, brown and green sandstones with some bands of grey-blue shales, which extend from Pickwell Down, near Barnstaple, to Wiveliscombe in Somerset. Fossil fish including *Holonema* cf. *ornatum, Bothriolepis, Polyplacodus* and *Holoptychius,* and fossil wood occur in the lowest beds. The beds represent the Famennian corresponding with the ' Psammites de Condroz ' of the Ardennes. They are succeeded by marine sandstones of green to yellow hues with shales and flagstones which extend inland from Baggy Point past Marwood and Sloley eastwards. At Marwood and Sloley the beds are fossiliferous, the littoral fauna consisting of *Ptychopteria*
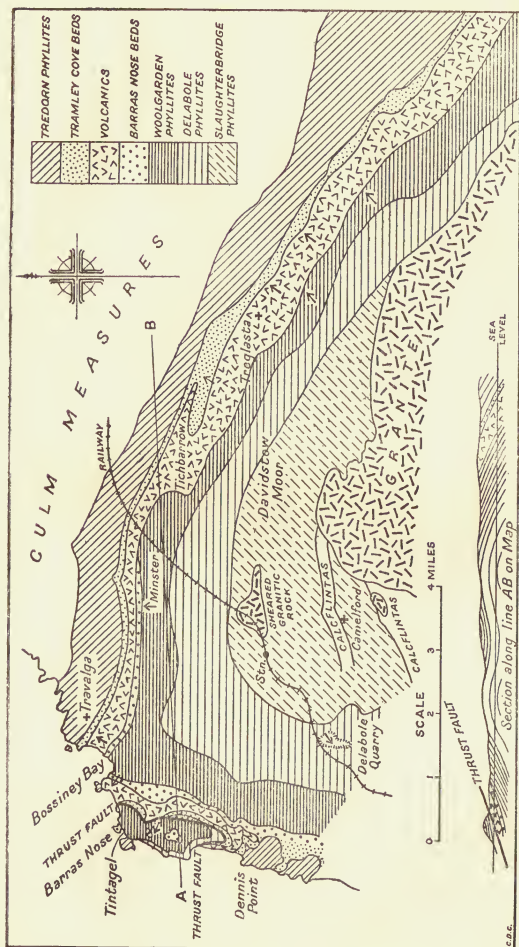
Fig. 7.—Geological map of North Cornwall.
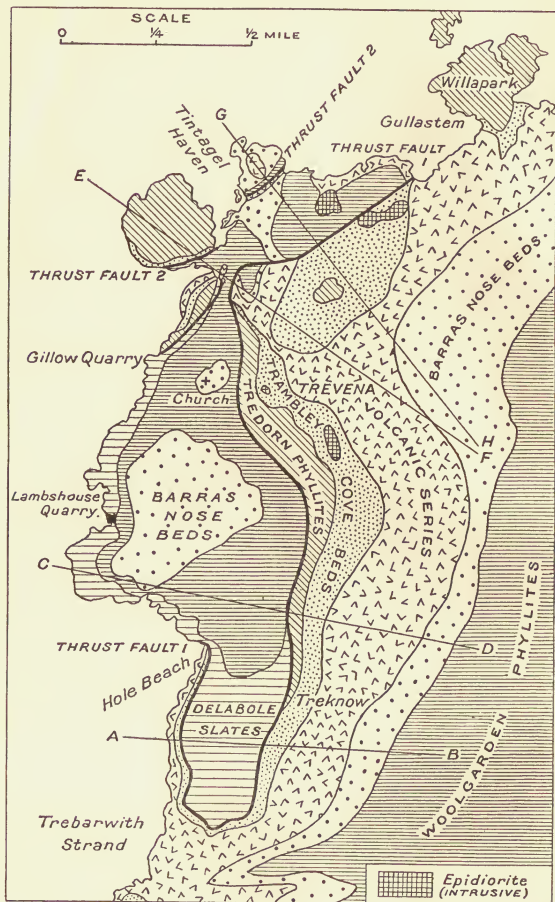
FIG. 8.—Geological map of Tintagel–Trebarwith area.

(*A*.5966)

A.—Hangman's Hill, near Bishop's Tawton: radiolarian cherts
[For explanation, *see* p. v.]

(*A*.5885)

B.—Zigzag-folded Culm Measures: Millook Haven
[For explanation, *see* p. v.]

(*A*.484)

A.—LITTLE ROUGHTOR, CAMELFORD
[For explanation, *see* p. v.]

(*A*.237)

B.—PORDENACK POINT, CASTELLATED CLIFF OF GRANITE
[For explanation, *see* p. v.]

(*A*.407)

A.—ROCHE ROCK, ROCHE. A QUARTZ-SCHORL DYKE
[For explanation, *see* p. v.]

(*A*.447)

B.—COOMB, ST. KEW. ELVAN DYKE
[For explanation, *see* p. v.]

(*A.*174)

A.—LANTERN CHINA-CLAY WORKS
[For explanation, *see* p. vi.]

(*A.*505)

B.—SLATE QUARRY AT DELABOLE, ST. TEATH
[For explanation, *see* p. vi.]

damnoniensis, Cucullaea unilateralis, Rhynchonella laticosta, Spirifer verneuili, Strophalosia productoides, Chonetes sp. and plant remains.

These beds pass upwards into the *Pilton Beds*, bluish-grey slates with thin bands of limestone and sandstone. The Pilton Beds follow the outcrop of the Baggy Beds from Barnstaple Bay to Somerset and are
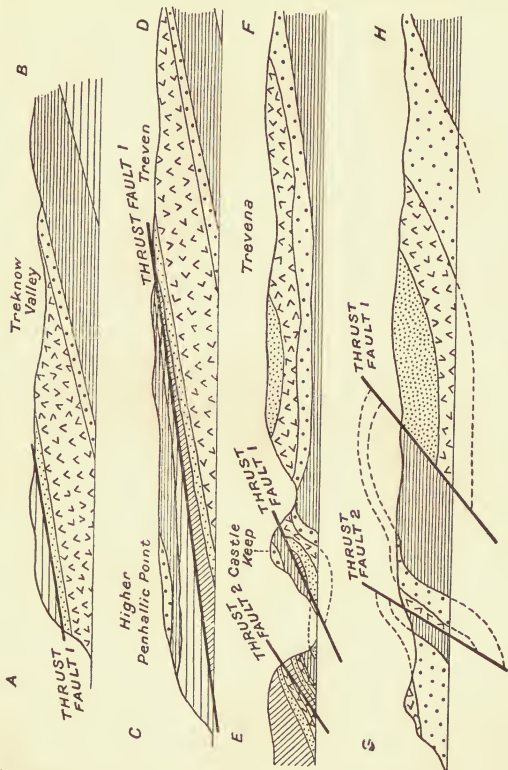
Fig. 9.—*Horizontal sections of Upper Devonian rocks of North Cornish coast.*

highly fossiliferous, but the fossils are often badly preserved. *Phacops accipitrinus, Productus praelongus* and *Spirifer verneuili* occur commonly, while *Loxonema anglicum* and other forms of gastropods also occur. The beds pass by insensible gradations upwards into the Carboniferous shales and contain a mélange of fossils belonging to the two formations, so that no definite line can be drawn.

C

North Devon and Tenby are the only districts in Britain where the passage from the marine Devonian into the Lower Carboniferous has been observed. In the Upper Pilton Beds the late Dr. A. Vaughan found in some black slates the fauna of the Zaphrentis Zone with the K fauna in the beds immediately beneath.

(c) PILLOW LAVAS, SILLS AND ALTERED ROCKS

Perhaps the most notable feature of Cornish Geology is the extensive and massive development of spilite in the Upper Devonian. Lavas form, in addition to square miles of outcrop near St. Minver, a continuous belt, over half a mile wide, for 25 miles inland (Fig. 4). Where exposed in cliff section or in quarries the structure is often seen to consist of a number of sack- or pillow-shaped masses reclining one upon another and mutually squeezing out of shape their symmetrical form (Pl. IV B). Where neighbouring pillows do not meet, siliceous or clay material or calcite fills up the spaces. Each pillow consists at the centre of a hollow : surrounding the hollow concentrically are zones of solid and vesicular rock, the vesicles increasing in size inwards. This pillow-structure is nowhere better seen than in the cliff face at Pentire Head (Pl. IV A). Seawards the lavas form headlands ; inland, hill ranges. Where the lava abuts against the Dartmoor granite it has been metamorphosed into a calc-silicate-hornfels. A great group of sills and perhaps some dykes are associated with the spilite : these consist of albite diabase, proterobase (minverite) and hornblende picrite. Near Polyphant the latter forms several large masses which have long been worked as the Polyphant ornamental stone and as roadstone. The similar picrite masses at Molenick, near Menheniot Station, also supply large quantities of good road metal.

The ferromagnesian minerals in the spilite are almost completely converted into chlorite, augite rarely remaining. In the albite-diabases augite is more frequently fresh, of a purplish hue and in ophitic relationship to the albite laths. Minverite, in addition to purple augite, contains also barkevikite (hornblende), and ilmenite and albite crystals play the role of ophitic plates. Central masses in spheroidally weathering diabase are often found to be non-ophitic and approach pegmatitic structure. Keratophyre and quartz-diabase are rare.

Contact metamorphism is conspicuous in the adjacent sediments, spilosite, some examples showing black crosses resembling chiastolite, and adinole being the characteristic changes. Adinole consists almost entirely of albite crystals and magnetite in grains, and some decomposed carbonates.

Where the calcareous sediments and the sills come within the area affected by the granite they have been converted into calc-hornfels, leptinolites and related rocks of great hardness. The shales have dark spots and ultimately crystals of andalusite, cordierite and chiastolite developed in them. Frequently they are found in the condition of andalusite mica schist. The calc-flinta found near Camelford and elsewhere contains in addition numbers of minerals that have arisen as a result of interaction between emanations from the granite and the older rocks : axinite, garnet, and vesuvianite being the commonest forms, while datolite and scapolite have been found at one or two places.

IV. CARBONIFEROUS ROCKS

INTRODUCTION

THE Carboniferous rocks of Devon and Cornwall have long been known as the Culm Measures on account of the occurrence in them at a few localities of soft sooty coal which in Devon is known as culm. The Culm Measures occupy an area of more than 1,200 square miles. Their outcrop on the north of the region (Fig. 5) extends eastwards from near Barnstaple to west of Wellington in Somerset ; and on the south from Boscastle to the east of Dartmoor (Fig. 4). The northern outcrop, although faulted in places and faulted out between South Molton and Brushford, is fairly continuous and there are no inliers of Devonian rocks ; whereas on the south the outcrop is much broken by thrusts and faults, and there are inliers of Upper Devonian rocks, while outliers of Culm Beds are found on the Devonian formation.

These measures are roughly divisible into the Lower Culm Measures and the Upper Culm Measures, the Lower forming only a narrow zone on both north and south of the great central area occupied by the Upper Measures. The Lower Measures comprise a series of dark shales with local slates, lavas, tuffs, limestones, cherts and grits : the Upper Measures consist principally of shales and sandstones, with rare nodules of limestone. Near Chudleigh and Newton Abbot at the base of the Upper Culm Measures there are beds of conglomerate in sandstones which rest unconformably on the cherts of the Lower Culm beds, and locally overstep them and lie on the Devonian rocks. The conglomerate contains pebbles of a granitoid rock unlike the granites of Dartmoor, of chert, and of decayed volcanic rocks.

(1) LOWER CULM MEASURES

(a) CORNWALL AND SOUTH DEVON

In Cornwall the Lower Measures extend from the coast south of Boscastle to Launceston and thence form an arc around the north of Dartmoor to Christow and flank the eastern edge of the granite mass southwards to Cornwood. A second outcrop extends from Alternun to Petertavy with a strike generally parallel with the northern crop, while an outlier forms the hilly ground around St. Mellion and St. Dominic. The order of succession of the beds is difficult to determine on account of overthrusts and inversions and differs on the coast from the inland localities. Near Boscastle black shales and fine sandstones are faulted against Upper Devonian slates and they extend northwards to Boscastle where some thin seams of lava are exposed in the cliff face. About two miles farther north beds of chert form the outstanding eminence of Fire Beacon. Similar beds of chert stretch discontinuously across the county in a series of whale-back ridges, arranged *en échelon*, past Otterham, Tregeare, Launceston, Lifton, Bridestow and Meldon to South Tawton.

The cliffs between Boscastle and Fire Beacon reveal many flat-folded masses, the curved beds of grit being described locally as fossil trees ; they pass insensibly into cliffs formed of intensely contorted slates, the Upper Culm Measures, near Cambeak (Pl. V B).

(b) NORTH DEVON

In North Devon another series of whale-back ridges extends east-wards from Codden Hill through Hangman's Hill and by Swimbridge towards South Molton, and gives rise to typical scenery well shown in Pl. V A. Fossils are rare in the Lower Culm rocks, but those that have been recorded are such as occur in the Viséan division of the Carboniferous Limestone. At Codden Hill, near Barnstaple, in the northern outcrop, a goniatite called by some authors *Prolecanites compressus* is common in the chert beds ; other forms include the trilobites *Phillipsia sp., Griffithides sp.*, and *Proetus coddonensis*, with species of brachiopods including *Chonetes*, crinoids and corals in addition to numerous radiolaria.

Associated with the beds of radiolarian chert on both crops are thin-bedded black limestones, which appear to occur both above and below the cherts. They contain locally the species *Posidonia becheri, Goniatites sphaerico-striatus* and other goniatites, more particularly near Fremington and at Venn and Swimbridge, near Barnstaple, and also at Brampton in North Devon, and near Wooladon and Lifton in the Launceston district. These goniatites are characteristic of division P of Bisat's classification of the Viséan.

Reddish and brown shales at Waddon Barton, South Devon, near Brampton in North Devon and south of Launceston, contain a distinct fauna, the principal feature of which is the great abundance of *Goniatites spiralis*, of which some thin layers of the shale are almost entirely composed. These shales are characterized also by a trilobite fauna, including four species of *Phillipsia*.

In North-east Devon another facies is developed along the conspicuous ridges of Westleigh, Canonsleigh and Holcombe Rogus where bluish limestones with intercalated cherts and shales contain among other forms *Goniatites mixolobus* and *G. spirorbis*. The radiolarian beds appear to rest on the Posidonomya beds in much the same order as in Cornwall.

Volcanic activity was widespread during the early Culm period and extensive sheets of spilitic lava and of tuff are associated with beds of radiolarian chert in North Cornwall, but no trace of them has been found in North Devon. These lavas are most typically in a sheared condition, but locally pillow forms have been preserved. The bold eminence of Brent Tor consists almost entirely of spilite in a brecciated condition, but where better preserved, large amygdaloidal and pumiceous masses are visible. The mass is probably 200 ft. thick. Manganese ores have been worked in the lava both in this district and at Lewannick.

Similar lava masses form much of the picturesque land near Launceston, and where the volcanic rocks abut against the Dartmoor granite they have been changed into calcareous hornfels in which the minerals axinite, vesuvianite and garnet are frequently observable.

(2) Upper Culm Measures

The Upper Culm Measures consist uniformly of dark-grey and greenish shales interbedded with sandstone and grit bands, and, more rarely, impure limestone in nodules and thin beds. From the lowest beds, near Exeter, goniatites characteristic of the middle part of the Millstone Grit of the North of England have long been known. These include the species *Reticuloceras inconstans* (Phillips). E. W. J. Moore (1929) has also collected from the neighbourhood of Fremington in North Devon *R. reticulatum* (Phillips) and *R. reticulatum* mut. α Bisat from slightly higher stratigraphical levels. Again from still higher horizons near Instow and near Clovelly, carbonate nodules often yield other goniatites such as *Gastrioceras subcrenatum* (Schlotheim MS.) C. Schmidt and *Anthracoceras sp. Gastrioceras listeri* is rarer but the lamellibranch *Dunbarella* [*Pterino-pecten*] *papyracea* is common, and these forms indicate the Lower Coal Measures age of the beds. The work of B. Simpson (1933) on the non-marine lamellibranchs of the Bideford district which indicate the presence of the zones of *Anthraconaia lenisulcata* and of *Carbonicola communis* would confirm this age assignment.

Fossil plants, although normally badly preserved, are not uncommon. The plants of the Instow Beds are represented only by forms of *Calamites*, which provide no criterion as to the age of the strata. The overlying Bideford and Bude Beds have yielded numerous plant remains, the most significant of which are *Neuropteris schlehani* Stur, *Alethopteris lonchitica* (Schloth.), *Mariopteris muricata ?* (Schloth.), *Sphenopteris striata ?* Gothan, *S. hoeninghausi* Brongn., and *Lepidophloios acerosus* L. & H. Many other forms occur in these beds and some may be of greater frequency than the more diagnostic species—for example *Calamites suckowi* Brongn. and *Calamocladus equisetiformis* (Schloth.). These beds clearly belong to the Lanarkian Stage of Kidston and are therefore equivalent to the true Lower Coal Measures as developed in other coalfields.

The Upper Culm sequence forms one division lithologically as it does palaeontologically, but as seen above there is no evidence either from the plants or the mollusca of the occurrence of the Upper Coal Measures.

V. GRANITES AND ELVANS

(1) NORMAL ROCKS

THE commonest igneous rock of Cornwall and Devon is granite. Apart from Exmoor nearly all the high moorlands are composed of this rock. Five great bosses trending south-west from Exeter to the Land's End rise above the lower slate country : namely, Dartmoor, Bodmin Moor, St. Austell or Hensbarrow, Carmenellis and the Land's End. Small bosses lie near the large ones ; Kit Hill and Hingston Down, near Dartmoor, Castle-an-dinas and Belowda, north of Hensbarrow, Carn Brea, Carn Marth and Godolphin on either side of Carnmenellis and, now isolated from Cornwall, the granite boss of the Scilly Isles.

There are several types of granite in each of the great bosses and these types are of slightly different ages from one another. Much of the granite consists of a rock with large porphyritic felspar crystals. Later than and intruded into this coarse-grained granite is a rock more uniformly crystalline and of finer grain, examples of which can be well seen in the Land's End and the Bodmin Moor areas. Later still are the dykes of aplite consisting of fine-grained quartz and felspar, and the dykes of pegmatite, coarse-grained rocks with large freely developed crystals of felspar, micas, quartz and some other minerals of subsidiary importance.

Of still later origin come the quartz-porphyry dykes, the ' grey elvan ' of the miner, which cut through both granite and sediments ; while the last group of intrusions consists of mica trap dykes.

In general the granites consist of quartz, large orthoclase felspar crystals and two micas, the black (biotite) and the white (muscovite) varieties. Tourmaline is of common occurrence and may be in some cases an original mineral. Cordierite, often replaced by secondary minerals (pinite) but retaining its original form, is by no means uncommon in the granite near the sediments, and andalusite is another mineral of frequent occurrence near the slate. In chemical and mineralogical composition there is a general agreement among the granites, but on the whole the Dartmoor granite is rather more acid than the others. Aplites are common everywhere, but pegmatite dykes are more restricted in their distribution and much more attractive on account of the large size of their crystals and the arrangements such as ' herring-bone ' and ' chevrons ' that these minerals have assumed.

The tourmaline pegmatite at Knill's Monument, near St. Ives, and the biotite pegmatite of Cligga Head are among the best developed. Formerly a pegmatite with biotite crystals measuring up to six inches in length was worked because of its lithia content at Trelavour Downs, near St. Dennis. Topaz and apatite are characteristic of some pegmatite dykes, and the clear blue topaz at Cligga and St. Michael's Mount are well known. An interesting example showing the relationship between the pegmatite dykes and the mineralized veins was brought to light in the wolfram openworks at the north end of Bodmin Moor where large

crystalline masses of wolfram formed a constituent of the orthoclase-quartz pegmatites, while at Kit Hill a quartz vein passes laterally into a molybdenum-quartz vein and finally into a cassiterite-quartz lode.

Not infrequently wide veins of quartz and schorl resembling dykes have broken through the sediments to form long steep-sided ridges traversing the country. Lanlavery Rocks, the Devil's Jumps and Grower Gut are cases, while Roche Rock (Pl. VII A) contains so much tourmaline associated with the quartz that it is black in patches.

The two groups of dykes—quartz-porphyry (or elvan) and mica-lamprophyre—are of general occurrence around the granites, the latter group extending farther away from them than the elvans. In some cases the elvan dyke forms a steep-sided ridge rising boldly from the lower ground of the sediment as at Coomb, near St. Kew (Pl. VII B). These dykes were intruded after the slates had been folded and also after the granite had baked the sediments, but in the case of the elvans before the cessation of the emission of vapours that mineralized the granite and themselves. For example, the elvan at Wheal Baddon is kaolinized. Some of the most handsome rocks of this group are the Tremore elvan, which is spangled with purple fluorspar, the pinitiferous elvan at Gold-sithney, the Prah Sands elvan and the flow-banded quartz felsite of Tregonetha. Most of the mica-lamprophyres are thoroughly decomposed, for instance those so clearly exposed in Newquay Headland and the Gannel, while others such as the Hicksmill and the Lemail dykes are fairly fresh biotite-orthoclase traps.

Locally the margin of the granite magma pushed out veins into the sediments and finely exposed sections of them occur near Cape Cornwall, Porthmeor, and Portheras Cove.

Although locally the roof of the granite mass has been preserved and the effect upon the granite by its proximity indicated by flow lines of felspar crystals there is practically no evidence of what has been termed ' overhead stoping ' by the magma.

The effect of weathering upon the granite can be studied among the tors and carns crowning the moorlands ; pseudo-bedding of the rock, well seen in many places (Pl. VI A), probably represents successive flows of molten rock. Dr. Brammall's papers record years of research upon this subject.

Inclusions of the country-rock highly altered by heat form dark ovoid patches in the coarse granite and are termed by the quarrymen ' furreners ' (foreigners).

(2) ALTERED ROCKS

All the granite masses are in part kaolinized, but the granite mass of St. Austell or Hensbarrow has suffered more than the other bosses. The mass covers an area of about 30 square miles and is fringed by the smaller domes of Castle-an-Dinas, Belowda Beacon, Roche Rock and St. Dennis.

China clay has been exploited in this district since the middle of the eighteenth century and the by-products of the industry form huge mounds of dazzling white quartz and other useless minerals, which are the characteristic feature of the scenery (Pl. VIII A). The eastern part of the granite is less altered and large quarries in fresh granite have long yielded

fine building and ornamental stone, especially at Gready, Colcerrow and Golden Point. This granite is coarsely crystalline, but fine-grained granite also occurs, as at Hensbarrow Beacon, while aplite veins are rare. The district is notable for the occurrence of pegmatite veins in which the component minerals attain an abnormal size ; one vein, at Tresayes, long worked for the manufacture of glass, traverses the slate and consists of large crystals of potash felspar up to 9 inches long by 4 inches wide and deep, quartz, tourmaline and, less commonly, gilbertite mica, fluorspar and pinite.

In the herring-bone pegmatite of Trelavour Downs, already mentioned, the black mica, or 'black shell,' contains up to 1·5 per cent of lithia.

Changes induced by the action of vapours emanating from the hot granite can nowhere be better studied than in this district. During its final stages of cooling at depth the granite gave off volatile gases above their ' critical temperatures ' ; these entered fissures in the consolidated granite and the adjacent rocks to give rise alike to the mineral lodes, the greisens, the tourmalinized rocks and the china clay. Great volumes of fluorine and boron were among these emanations, along with sulphur dioxide, superheated steam and carbon dioxide.

As a result of these emissions three main types of alteration of rock bodies can be recognized, namely : (1) Tourmalinization, (2) Greisening and (3) Kaolinization ; but they overlap and are not always distinct from one another. The vapours reacted upon the minerals of the rock in different ways.

(a) TOURMALINIZATION

In the process of tourmalinization the original felspar and micas suffered ; where mica was replaced a tourmaline-granite was formed ; but frequently the process continued and the felspars also were replaced so that a quartz-schorl rock was all that remained of the original granite. The most outstanding instance of tourmalinization is Roche Rock (Pl. VII A), but similar reefs form bold features as at Devil's Jumps, near Camelford, and Lanlavery Rock, north of Bodmin Moor. Varying degrees of tourmalinization of granite can be seen, as in 'luxulyanite', 'trevalganite' and 'trowlesworthite'—the last rock also containing fluorspar. Veins of tourmaline and quartz cut the kaolinized granite in all directions and offer hindrances to the clay workers by whom they are called among other terms, 'stent.' Their mode of occurrence as veins traversing the kaolinized rock indicates an origin earlier than the kaolinization.

Luxulyanite was originally a porphyritic granite, and the phenocrysts of pink felspar stand out in striking contrast to the dark blue groundmass of quartz and schorl. Its value as a decorative stone may be gauged by the tomb of the Duke of Wellington in St. Paul's Cathedral. Tourmaline is rich in boron, containing as it does up to 10 per cent of boric acid. Boric vapours attacked the calcareous muds and limestones adjacent to the granite and partly converted them into axinite and garnet rocks, as at Tremore ; where lime was absent a quartz-schorl schist was formed that retained the structures of the sediment.

(b) GREISENING

Where fluorine was the active vapour the granite became greisened ; the felspars were converted into aggregates of quartz and white mica, usually a lithium-bearing variety which may also contain fluorine. Greisens are the repositories of idiomorphic crystals of topaz and fluorspar, but tourmaline does not occur. Greisen veins in the granite have been worked for tin as at Beam and Bunny near St. Austell. The process of greisening appears to have operated earlier than that of kaolinization.

(c) KAOLINIZATION

Probably the last of the series of processes of alteration (pneumatolysis) caused by these active vapours and mainly by carbonic acid was that of kaolinization or change into china clay. The crystals of potash felspar have undergone the greatest change and under the microscope they can be seen to consist of an aggregate of minute scales of kaolinite with some secondary felspar and quartz. The large crystals (phenocrysts) of felspar were more resistant than the matrix to this change and often have remained unchanged or only partly altered in a rock that crumbles down in the hand to powder. Strangely enough, however, locally they were completely converted into masses of kaolinite retaining the original crystalline form of the felspar. Such specimens are normally twinned and are called by the clay workers ' pigs' eggs.'

Kaolinization in the St. Austell granite has been effected along fissures trending from north-east to south-west, in alignment with the tin-bearing veins (Fig. 10), and the great pits have been developed along these fissures (Pl. VIII A).

From evidences derived from this region there is very little support for the view that kaolinization was due to atmospheric agencies—all the evidence supports a pneumatolytic origin depending largely on carbon dioxide.

The trade processes by which the clay is prepared for the market are illustrated in the museum show cases and a long account of them would be out of place here, but it is the usual practice to employ hydraulic mining. The soft kaolinized rock is broken up by strong jets of water under pressure and washed down to the bottom of the excavation. In this way the constituent minerals, quartz, white mica and kaolin, are separated. The lighter minerals are pumped up to the surface into a series of settling tanks ; the heavier quartz is dug from the pits and conveyed in elevators to the dumps of waste. The fine white mica passes through two groups of tanks : in the first the waste material is trapped and thrown to waste, whilst the commercial mica flows into the second group, where it gradually settles down in the water. The water carrying the kaolin runs on into a third group of tanks or pits where the china clay settles, to be dug out and conveyed to drying floors.

China Stone.—Some areas of this granite mass have been changed in a different manner, which probably resulted from a different mineral composition of the original rock, and resulted in the formation of china stone. The area so affected is indicated on Fig. 10. China stones are pale-coloured rocks, often tinged purple by fluorspar, and are classed

according to their hardness as 'hard purple' and 'mild purple,' whilst those devoid of fluorspar are grouped as 'hard white' and 'mild white.' A weathered material called 'buffstone' was the rock first worked.

The rocks consist of white mica, in both primary large plates and
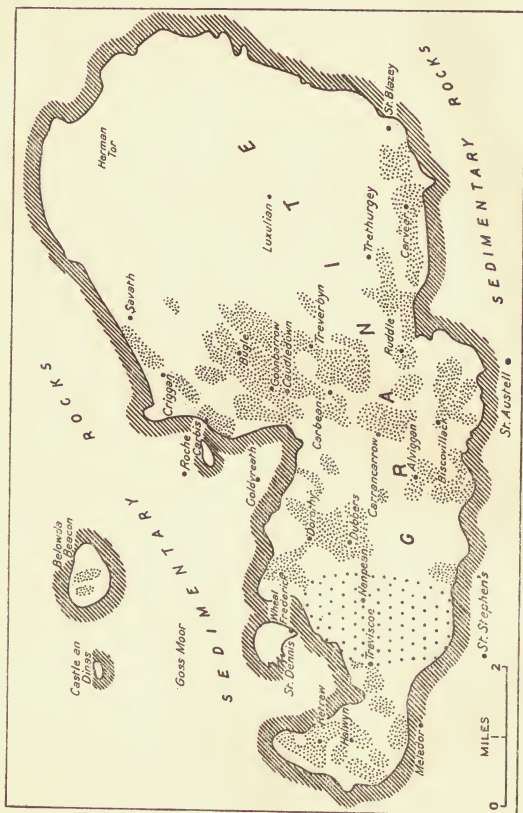
Fig. 10.—*Map of the St. Austell granite mass, showing kaolinized areas. The China Clay area is shown by large dots : the China Stone areas by small dots and the unaltered granite by white.*

small clustered scales of pneumatolytic origin, of the varieties lepidolite and gilbertite, but neither biotite nor tourmaline has been recorded. Primary albite felspar forms small idiomorphic crystals often enclosed in quartz, and microperthite is abundant. Topaz is so frequent that it

would appear to be an essential component : it occurs as large compact primary grains. In some varieties purple fluorspar forms much of the rock and often is seen to spread along the cleavages in the muscovite plates.

All the best china stones have resulted from pneumatolytic processes but in the harder rocks the change has reached only to the extent of the replacement of felspar by white mica and the introduction of fluorspar. Except in the soft stones kaolinization has not greatly affected the felspar crystals.

These changes appear to have been brought about by the action of fluorine and lithium upon a rock that was richer in albite than is the normal granite.

The commercial processes consist principally in grinding down the rock into powder, from which the best porcelain is manufactured. The abundance of albite and fluorspar and the absence of biotite and tourmaline increase the commercial value of the rock by rendering it more easily fusible.

VI. NEW RED ROCKS

THIS title includes the rocks shown on the map (Fig. 11) as Permian and Trias. They constitute a great part of the cliffs between Paignton and Sidmouth and give rise to the famous ' good red earth ' of Devon and Somerset. The general red colour forms a pleasing contrast with the green of the foliage, and much of the charm of Devonshire scenery is due to it.

On the whole the beds are unfossiliferous and it is only by their lithology and sequence that they have been separated into the Permian and the Trias. De la Beche and Godwin-Austen described them under the title of the New Red Sandstone Series ; earlier, Conybeare and Buckland, struck with their likeness to the Rothliegende of the Hunsrück district, grouped them as Permian, and Murchison entirely agreed with this view. Among later workers Irving, Ussher and Whitaker must be especially mentioned.

(1) PERMIAN ROCKS

Although it has always been considered probable that the lower beds, including the Exeter Volcanic Series, represent some of the Permian horizons of Germany there has been a great difference of opinion as to the upward limits of the Permian in Devonshire. The Budleigh Salterton Pebble Bed has been taken as the equivalent of the Bunter Pebble Bed of the Midlands and all the red rocks lying below it as belonging to the Permian ; while other writers regard the whole series as Keuper.

Irving suggested that the division should be made at the base of the Pebble Beds.

Ussher adopted Irving's classification of the Permian rocks :—

						Ft.
(4) Red marls with local sandstone –	–	–	–	–	about	700
(3) Red sandstones and breccias	–	–	–	–	–	450
(2) Breccio-conglomerates and boulder breccias			–	–	–	950
(1) Watcombe clays and sandstone (shale paste)			–	–	–	0–200

After the Carboniferous rocks were deposited, desert conditions prevailed and a great thickness of angular debris and coarse sand was swept down from the heights to accumulate as fan deposits in a basin now bounded on the west and north by Dartmoor, Exmoor and the Quantocks (Fig. 11).

The angular debris or breccia rests upon Palaeozoic rocks, and many of the angular fragments have been derived from the older beds. The Dartmoor granite mass and the covering sediments appear to have been undergoing denudation while the upper breccias were being formed, for masses of quartz-porphyry fragments occur in those breccias.

(1) The Watcombe Clays seem to be the earliest New Red deposits exposed at the surface and on the coast have a well-defined position subordinate to the breccio-conglomerates amongst which they are brought

FIG. 11.—*Geological sketch-map of the New Red rocks of Devonshire and West Somerset.*

up by faults. They occupy small areas near Watcombe, Barton and Daccombe, between Teignmouth and Bishopsteignton. The dark red clays have long been used for the local terra-cotta ware, and for tiles and bricks.

(2) The breccio-conglomerates and boulder beds are naturally divided into a lower part, of which by far the greater proportion of the fragments consists of fossiliferous Devonian limestone ; the remainder in order of importance being fragments of sandstones, rocks resembling Permian felspathic trap, and a few pieces of vein quartz. These beds form the grand cliffs between Babbacombe and the estuary of the Teign, while huge blocks lie scattered at the base of the cliffs on the foreshore. The higher breccias contain a large number of volcanic rocks, some of the blocks being of great size. Long lists of the rocks represented in the fragments of these breccias have been published : by far the commonest rock is a peculiar red quartz-porphyry. The breccias extend to Dunchideock and Ide. Sheets of lava lying at the base of the breccias indicate the activity of contemporaneous volcanoes ; a notable fact, however, is that the composition of these lavas is different from that of the lavas found in the breccias : it appears therefore that the two sets of lavas may belong to different centres of vulcanicity.

Breccias form a narrow band in the Crediton valley extending westwards across the Tawe. North of Silverton they pass into loose gravels (for a long time thought to be drift deposits), composed of a different suite of rocks, which probably owe their origin to a source lying north of the area.

(3) In the Exeter district the breccias are gradually succeeded by sandstones and these in turn pass up into (4) red marls with lenses of sandstone. Their underground extent eastwards below the Trias is unknown. The fine coast section between Exmouth and Straight Point consists of these marls and the intercalated thick and thin beds of sandstone, much cut up by faults. At Straight Point a fault brings in a series of marls at least 500 ft. thick, but without sandstones : these beds pass conformably under the Pebble Beds near Budleigh Salterton.

Outliers of Permian rocks occur between Bolt Head and Plymouth, and similar rocks have been dredged from the sea in South-east Cornwall, so that the Permian must have formerly covered a considerable area to the south.

It is a notable fact that no rocks occurring in the breccias can be ascribed with certainty to the Dartmoor granite and its contact, the wellknown fragments of ' murchisonite ' felspar, a flesh-red variety of perthitic orthoclase, not being sufficiently characteristic to indicate such an origin.

(2) Triassic Rocks

The Triassic rocks are admirably exposed along the range of cliffs between Budleigh Salterton and Sidmouth. The beds rest upon the Permian marls without any sign of unconformity, although the Lower Mottled sandstones of the Midlands do not appear to be represented.

In the following figures the thicknesses are only approximate :—

						Ft.
(2) Coarse red sandstones –	–	–	–	–	–	350–400
(1) Pebble Beds or conglomerate		–	–	–	about	80

(1) The Pebble Beds (Pl. IX A) consist of 70 or 80 ft. of strata made up of pebbles and occasional subangular stones of quartzite, grit and quartz, in a dark red and sometimes grey and buff matrix of sand. Seams of sand without pebbles are not uncommon. Fossils were discovered in some of the quartzite pebbles in 1863 by Vicary and were described by Salter. Among the species *Lingula lesueri* occurs, a form characteristic of the *Grès Armoricain*, and *Orthis budleighensis*, which occurs in the *Grès de May* of the Ordovician of North-west France. Pebbles of Devonian rocks containing *Spirifer verneuili* and *Homalonotus sp.* also occur. Hard tourmaline rocks which resemble those of the metamorphic aureoles round the Cornish and Devon granite masses are fairly common. To account for these foreign pebbles, which decrease in numbers as the beds are traced northward, Ussher suggested a derivation and transport from the south. This suggestion is supported by H. H. Thomas's work on the heavy detrital minerals that occur in the deposit.

Inland the Pebble Beds form an escarpment, with its easterly dip slopes marked by waste land covered with heather which contrasts with the rich grass lands of the lower beds. The conglomerate can be traced through Devon into Somerset, but the pebbles become smaller and there are fewer of quartzite. Northwards they are replaced by grit, quartz and Carboniferous Limestone, and these increase notably near Williton. Laterally the bed passes into sandy gravel with small pebbles of grit and quartz. It has been suggested that the pebbles were conveyed by rivers draining land now submerged below the Channel, and by other rivers flowing from the north and west which united near Burlescombe : an alternative view is that they formed a ridge of pebbles with a river lying to the north of it.

Overlying the Pebble Beds are coarse current-bedded red sandstones, the lower 100 ft. containing a few pebbles of quartz and quartzite. More massive sandstones, well exposed between the mouth of the river Otter and Sidmouth, succeed ; bones of *Hyperodapedon sp.* have been found in these sandstones.

It is difficult precisely to define the base of the Keuper Series ; it has been taken as the hard breccia at Sidmouth. Pale red and grey sandstones with seams of marl overlie the breccia and are in turn succeeded by red marls with thin sandstones in the first 150 ft. and massive bedded marls containing gypsum and common salt above. These beds constitute the lower parts of the cliffs eastwards to Branscombe Head, but a syncline near Beer Head carries them below the beach.

The Keuper Marls are of great thickness inland, a boring at Puriton, near Bridgwater, proving a thickness of 1,350 ft. Salt was obtained from the brine here for a few years.

In the cliffs of West Somerset the Keuper Marls are well exposed. Where the Keuper Beds rest on Carboniferous Limestone a conglomerate occurs which is known as the ' Dolomitic Conglomerate ' : it has been worked locally for the ores of zinc, lead and iron.

(3) RHAETIC SERIES

Higher beds overlain by the Rhaetic series come in along the Axmouth and Bindon cliffs. Towards the top of the red marls there is a layer of

hard pale grey to buff banded marl with streaks of dark clay which marks the incoming of the sedimentary conditions which characterize the Rhaetic formation. The following section at Culverhole shows the local sequence of the Rhaetic Series :—

		Ft.
White Lias	Top beds, obscured – – – – –	10
	White limestone, thin bedded with pebbles or concretions of compact limestone near the base: *Arca* and *Modiola minima* – – – –	15
	Impersistent masses of ' Landscape stone ' or Cotham marble – – – – –	¾
Black *Avicula-contorta* Shales	Black shales with ' *Avicula contorta*,' ' *Cardium rhaeticum* ' and other forms ; at the base a bone-bed with reptilian bones and numerous fish remains and coprolites : – – about	18
Grey Marls (passage beds)	Green marl : surface cracks infilled with fish remains – – – – – – – –	10
	Alternations of pale greenish and cream coloured marls, with marly limestones and black clays	20

The full thickness may be obscured by the White Lias which has slipped over the upper part of the Black Shales.

(4) THE EXETER VOLCANIC SERIES

In the neighbourhood of Exeter several kinds of volcanic rock lie near the base of the New Red Series. They in part represent lava-flows, the surface outpourings of deep-seated reservoirs of rocks rich in potash. Most of the lavas are trachytic, while some are allied to basalt. They were originally examined by Ussher and Teall and later by Hobson and Hatch. Their original mineral constituents appear to have been orthoclase and plagioclase felspars, biotite, augite and olivine. Although the felspars retain their original characters the other, ferromagnesian, minerals are almost completely decomposed. Biotite mica, however, is often unchanged. Olivine has not been seen in an unaltered state, but a characteristic red mass consisting of iron oxide and iron carbonate, which has been called iddingsite, represents it.

These rocks, known as ' traps,' can be grouped into several distinct types, although transitional forms also occur, and the name of the locality where each type has been found is applied to the rock. The names of the different volcanic masses and the distribution of the rocks are shown on map (Fig. 12). In recent years the group has been classified by Tidmarsh into the following three series :—

(i) The Hatherleigh Series, in which the xenocrysts include quartz, felspar, pyroxene, biotite, iddingsite, and apatite ; (ii) the Pocombe Series in which the xenocrysts are restricted to biotite and iddingsite ; and (iii) a group of unrelated potassic types with varying assemblages of xenocrysts.

The first two series comprise basaltic, intermediate and lamprophyric types : the third group consists of basic minettes.

Tidmarsh considers that these rocks are ' hybrids ' resulting from the admixture of a late acid residuum and the depth residuum of the Dartmoor igneous mass.

The Hatherleigh Series comprises the following rocks :—

(*a*) The Dunchideock type which includes grey and purple fine-grained compact basalt in which quartz inclusions are occasionally present. The Posbury rock is a purplish brown and finely vesicular variety. (*b*) The Westown type is normally a purple-brown basalt with corroded quartz and with vesicular and porphyritic margins. (*c*) The rock of Killerton is a grey mica-lamprophyre or minette, consisting of a fine crystalline groundmass of small orthoclase felspar through which brown mica flakes lie scattered.

The Pocombe Series consists of (*a*) the Thorverton type, a rather
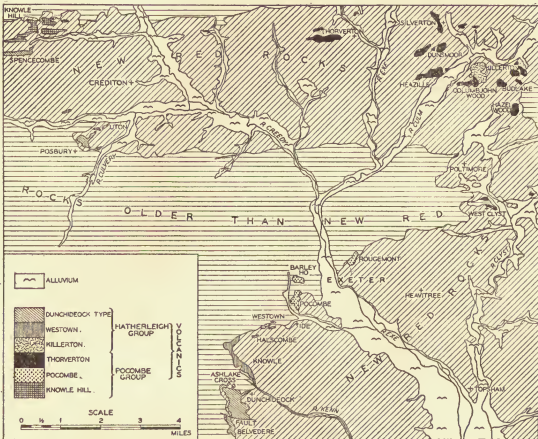
Fig. 12.—*Map of Exeter district showing distribution of Volcanic and New Red rocks.*

coarse-grained purple basalt which is vesicular near the base of the flow ; (*b*) the Pocombe type, a dark blue-grey basic rock traversed by veins of calcite and dolomite called ciminite or trachyandesite, and (*c*) the Knowle type, a hard compact blue-grey minette with vesicular margins.

The notable characteristic of the Exeter traps is the association of basic plagioclase felspar with quartz, and of orthoclase felspar with olivine. Their field relationships are obscure but sufficiently well seen to prove a Permian age. The rocks are only small remnants of their former masses. Great quantities of igneous rock fragments occur in the breccias, but even if these are added this Permian volcanic episode was feeble when compared with the contemporaneous volcanic activity in Western Germany.

D

VII. MINES AND MINING

(1) **Stream-Tin**—Following the erosion and disintegration of metal-bearing veins by rain and frost, the crystals of cassiterite (oxide of tin) and country rock were transported in the form of rolled pebbles to low ground and there deposited in gravel beds.

Early man discovered by their weight and, perhaps, by accidental heating in fires, that these pebbles contained tin, and that others were copper bearing. By firing the mixed ores bronze may have been discovered.

Tin has been exploited in Cornwall and Devon from a period probably as early as the Bronze Age (1800 B.C.). The Phoenicians probably visited Gaul and Cornwall for purposes of trade, and in the Roman period knowledge of the occurrence of the mineral veins led to underground mining.

The search for pebble- or stream-tin was mainly carried on in the lower parts of the rivers, especially at Carnon, Par and Pentuan, though tin was also sought for in the upland marshes. These deposits are mainly the accumulations carried by floods during the Glacial period, which swept down disintegrated country rock and mineral vein material. The tin-bearing gravels are covered with a succession of land surfaces separated by marine deposits. In the working of such deposits the buried river channel was carefully followed along its course and the worked-out areas now present the aspect of huge winding trenches only partly obscured.

(2) **Mines.**—In tracing these tin-bearing gravels towards hilly ground early man would have encountered the outcrops or ' backs ' of the lodes and there he commenced to extract the mineral-bearing substances from the rock.

Mining in Cornwall has thus been carried on from very early days, and it is usually supposed that Ding Dong Mine in the Land's End peninsula was worked by the Romans.

Fig. 13 shows that the areas of mining are more or less confined to a zone of mineralization about ten miles wide, which trends north-east from Land's End to North-east Cornwall.

At the present time the principal centre of mining lies around Camborne and Redruth (Fig. 14), but regions of former intensive exploitation lie near St. Just-in-Penwith where the lodes were traced beneath the sea for a distance of about a mile from the coast (Fig. 15), the St. Ives–Mounts Bay, the St. Austell, the Caradon and Liskeard, the Kit Hill and the Western Dartmoor areas.

The mineral lodes are intimately related to the granite masses that were intruded in Permo-Carboniferous times. In addition to tourmalinization, kaolinization and greisening (already described), another effect of vapour action was the infilling of fissures in the country rock by metallic compounds and earthy minerals (gangue).

These infilled fissures are the lodes. Other types of ore-bodies are the ' stockwerks,' in which the country rock—both sediment and granite—
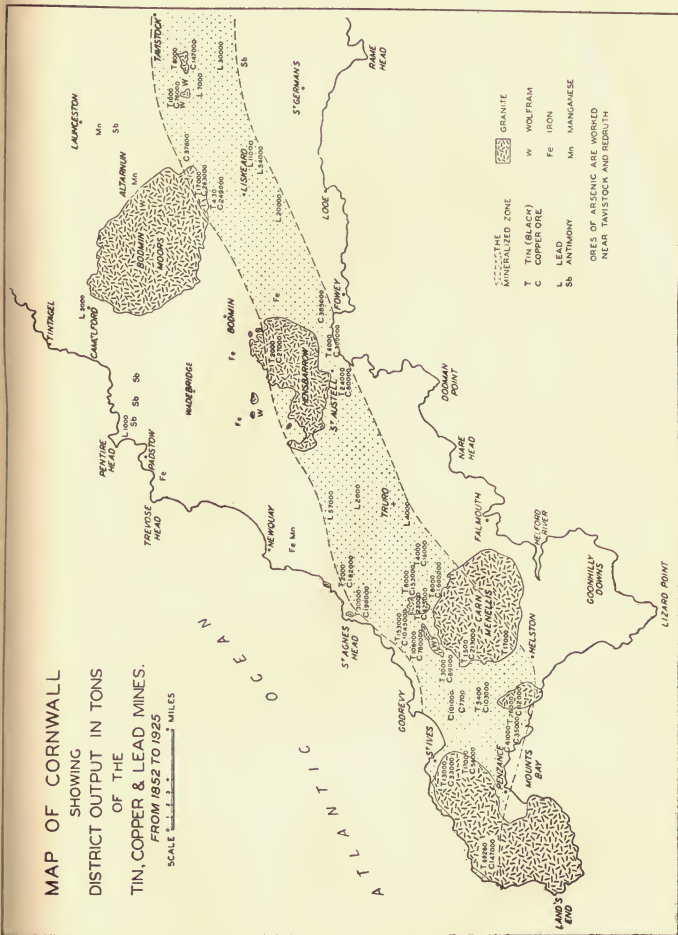
Fig. 13.—Map of Cornwall showing mineralized tracts and district outputs of ores from 1852 to 1925.

was permeated by vapours to form ' stringers ' : when the country rock is a greisen, as at Cligga Head and St. Michael's Mount, or kaolinized granite, as at Bunny, St. Austell, the ores in the stringers are cassiterite

FIG. 14.—Map of the principal lodes and mines in the Camborne, Redruth and Scorrier districts.

and wolfram ; in slate, as at Mulberry open-works, Lanivet (Pl. X B), cassiterite crystals are seen on joint faces.

(3) The Lodes.—Vapours and solutions arising from the solidifying

granite gave rise to the ore bodies. These emanations probably consisted in great part of stannic fluoride, steam, carbonic acid, boric acid, and sulphuric and other acids. Stannic fluoride is supposed to have reacted upon steam to form tin oxide and fluoric acid, which in turn attacked carbonate of lime to form calcium fluoride or fluorspar.

The ores contain metallic compounds (*e.g.* tin oxide, copper sulphide, etc.) that are commercially workable.

These ores are enveloped in such minerals as quartz, fluorspar and barytes, also tourmaline and chlorite. These minerals, known as gangue, are usually of little commercial value and normally are rejected.

The lodes trend generally nearly east and west, and roughly parallel with the range of the granite masses. They may underlie northwards or southwards, and in West Cornwall those underlying to the south displace those underlying to the north, as well as the elvan dykes, the slates and the granite. These effects are well seen in the section of East Pool Mine (Fig. 16). In those lodes which underlie to the north an abundance of mixed sulphide ores (chalcopyrite and pyrites) occur in association with arsenide (mispickel) and tungstates (wolfram and scheelite) but are less
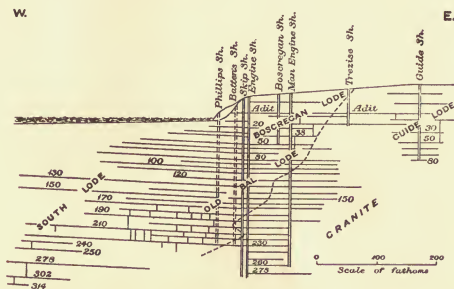
FIG. 15.—*Levant Mine. Longitudinal section showing levels and workings.*

rich in cassiterite than the lodes which underlie south. The latter, on the contrary, are poor in sulphides, arsenide and tungstates.

The gangue minerals also present group characters, quartz with some schorl occurring more frequently in the north dipping lodes, while those dipping south consist of chlorite-peach (p. 48) and some fluorspar.

In East Cornwall and Devon there is less difference between the two groups of lodes.

It appears probable that the infilling of the north-dipping lodes preceded the faulting which affects them, whereas that of the south-dipping lodes occurred later but not necessarily after a long period.

The veins are not uniformly rich in metallic substances but vary in the amount they contain both laterally and at different levels below surface. To test the value of a lode assays are made of materials taken at frequent intervals. The results are expressed as the ratio in pounds of the metallic substances to tons of the earthy materials, taken from a

measured width of the lode. Where the proportion of tin oxide to earthy materials falls below 20 lb. per ton it is generally found to be too low to repay the costs of mining, unless other metals are present such as copper, tungsten and arsenic.

Lodes are either mineral infillings of clean-cut faults, or mineralized fault breccias, or mineralized fractured rocks on both sides of fissures. Large masses of rock lying in the lodes are termed 'horses,' while cavities lined with crystals are known as 'vughs.' The finest crystals have been recovered from vughs. The dense crypto-crystalline and massive ore bodies are the most sought after by the miner.
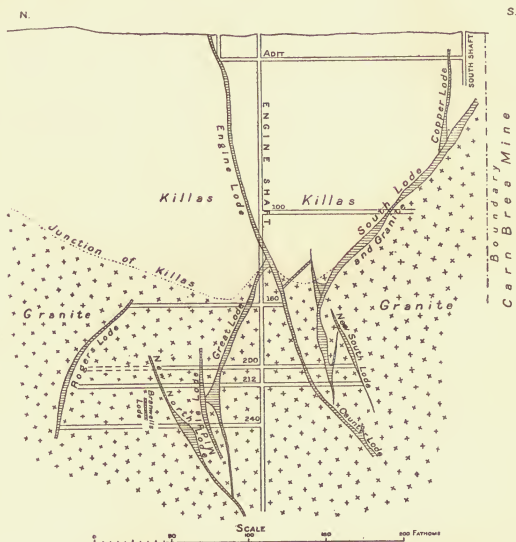
FIG. 16.—*Horizontal section of part of East Pool Mine, Illogan.*

Black tourmalinized and silicified country rock has been called by some miners 'peach'—it often yields payable amounts of tin ore when it forms 'capel' on the margins of the lodes. The term peach is, however, more usually applied to the soft dark green chloritic aggregates in lodes. 'Gossan' or gozzan is the weathered part of a lode, immediately below which the sulphide ores are often richer than elsewhere (the zone of secondary enrichment).

(4) Mineral Zones.—The accompanying map (Fig. 13) indicates the position of the mining centres and the nature and quantity of the minerals raised from the mines of these centres between the years 1852 and 1925.

Conspicuous features of the map are the crowding together of the tin and copper mines near the granite masses and the occurrence of lead, zinc and iron mines in regions farther away from those masses.

It also shows that the mines are not evenly distributed around the granite, but lie along a tract of ground about ten miles wide that traverses the country from south-west to north-east. In this tract the several mineral zones form, as it were, concentric belts around emanative centres, that nearest the granite bearing tin, the next bearing copper, then belts of zinc and lead, and finally areas where iron has been worked.

These zones of minerals have also been proved in the individual mines as they were worked downwards. Such changes were found while Dolcoath
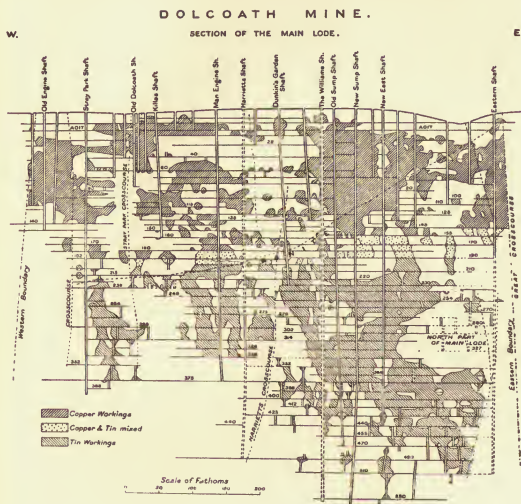
FIG. 17.—*Section of the Main lode, Dolcoath Mine, Camborne.*

(Fig. 17) was worked, the upper levels yielding some zinc with copper ; then down to 170 fathoms copper alone ; between 170 and 190 fathoms mixed ores of copper and tin, and from 190 fathoms down to 550 fathoms, the bottom of the mine, tin alone.

As in the higher levels at Dolcoath, zinc and some galena were also worked at Tresavean, while at Wheal Mary Ann, Liskeard, galena and blende were exploited to a depth of about 300 fathoms where the incoming of copper ores corresponds with the diminution of those of lead and zinc. This depth roughly indicates the thickness of the zone of lead and zinc. Farther away from the granite, carbonates form the upper parts of the lode material, siderite and calcite occurring in the iron mines on the Perran

lode and elsewhere, with galena lower down. Fig. 18 indicates the vertical distribution in zones of ore bodies and gangue minerals, and the approximate temperatures of their formation.

The change of mineral content found as the mines were deepened was not confined to the ores but was also characteristic of the gangue minerals. Quartz or 'spar' occurs from the lowest level to the surface,

VEINSTONES OR GANGUE MINERALS	MINERAL ZONES	THICK-NESSES IN FEET	APPROXIMATE TEMPERATURES OF FORMATION IN DEGREES C.
	ZONE OF CARBONATES (IRON, MANGANESE ETC.)	400	UP TO 150
	ZONE OF SULPHIDES OF ANTIMONY, ETC.	200	
	ZONE OF SULPHIDES OF LEAD AND SILVER. GIVING PLACE AT DEPTH TO ZINC AND COPPER.	1800	400
	ZONE OF SULPHIDES OF COPPER, INTERMIXED WITH WOLFRAM AND TIN FOR SOME 700 FT. AT BASE	2500	500
	ZONE OF OXIDE OF TIN WITH WOLFRAM IN THE UPPER PARTS	2500	550 TO 575

FIG. 18.—*Diagram of vertical distribution of the Mineral Zones of Cornwall.*

but tourmaline is met with mainly in the tin zone, it giving place to fluorspar with the incoming of copper ores. Barytes is mainly associated with lead ores, while arsenic compounds occur with copper, tungsten with tin.

(5) Secondary Enrichment.—The enrichment of ores in the deeper parts of the mines was brought about by a natural process in which

percolating rainwater, carrying carbon dioxide, while passing downwards dissolved the copper sulphide of the original chalcopyrite in regions where sulphates and chlorides now occur, and precipitated it on chalcopyrite from acid waters in parts of the lode free from oxygen. The change led to an increase in the proportion of copper to sulphur.

As a result of this solution the upper parts of the lodes, sometimes down to 150 fathoms below the surface, consist of gangue minerals with iron oxides which form the ' gossan ' or ' iron hat ' of the miner.

This zone passes gradually into that of zone (2) or the zone of the black and the red oxides and the blue and the green carbonates of copper. Uranium minerals have been found in this zone in a few mines and have been worked commercially at Trenwith and South Terras mines. The oxide zone passes in turn into zone (3) or that of secondary enrichment where chalcopyrite has been converted into the vitreous ore, called also redruthite, chalcocite, or copper glance, while at still greater depths, beyond the reach of concentrating waters, primary chalcopyrite may remain.

The amount of enrichment is marked by increasing proportions of metallic copper. Chalcopyrite, the original ore, contains 34·5 per cent of copper ; this is converted into erubescite or bornite with 55·58 per cent, and, finally, into chalcocite with 78 per cent of copper.

(6) Economics.—Cornwall owes its mineral wealth mainly to the granite and the emanations from it, for the mining and the china clay industries alike depend upon them. The search for minerals has led to the removal of immense quantities of rock both from surface and underground workings, more particularly in the case of stockwerks, which are necessarily worked open-cast. A huge excavation for tin ore of this nature is shown on Pl. X B, a photograph of the famous Mulberry openworks. Pl. X A illustrates a lode partly stoped away underground at a depth of 412 fathoms in Dolcoath Mine and is typical of Cornish lode-mining.

The extraction of tin ore depends upon the market price and the industry has suffered many vicissitudes from changing values of tin during the last 100 years ; between the two wars the annual output ranged from a minimum of 920 tons to a maximum of 5,640 tons. This uncertainty of price, coupled with the cost of keeping the mines unwatered, adds greatly to the difficulties of the miners.

Hydraulic methods are employed for the extraction of china clay and mica clay from kaolinized granite and Pl. VIII A (the Lantern china-clay works) is an example of an openworks. The refuse dumps, consisting mainly of quartz, in the process of being built up are shown in the background. The output of china clay from Cornwall and Devon for 1933 amounted to 597,000 tons, and of mica clay some 8,000 tons.

Quarrying of granite and other igneous rocks and of slate is also an important industry. During the year 1933 some 1,216,000 tons of igneous rock were raised ; of slate, 17,474 tons were recorded, the bulk of it from the famous Delabole quarries in North Cornwall. This great quarry has been in work since the Elizabethan period and now presents a huge openworks upwards of 500 ft. deep. Pl. VIII B is a view of it looking north down the incline to the bottom of the quarry. The strong cleavage dip is well illustrated. The number of people employed in

1933 as miners and quarrymen amounted to 8,300, exclusive of those engaged in the china clay industry.

The Oligocene clay at Bovey Tracey (see p. 61) is used in the manufacture of glazed fire bricks and other wares.

VIII. CRETACEOUS ROCKS

(1) INTRODUCTION

CRETACEOUS rocks crop out on the eastern margin of the area, where they consist of the following broad divisions (Map, Fig. 19) :—

Chalk
Greensand
Gault

Although these names suggest that the sequence is similar to that which is found in the south and south-east of England, there is a notable difference between the sequences both in the thicknesses of the beds and in their lithology ; for example, beds that are mainly clay in south and south-east England consist principally of sand in Devon.

The Cretaceous Beds on the whole form high ground extending as a more or less dissected sheet from Lyme Regis to Chard on the east, and from Sidmouth to the Blackdown Hills on the west ; the Haldon Hills, south-west of Exeter, consist in part of greensand, while a small tract at Orleigh Court, west of Bideford, constitutes the westerly limit of the formation.

On the eastern margin of the area the Cretaceous rocks rest unconformably upon the easterly-dipping Lias, farther west they overlie the Trias (Pl. XI A), on the Haldon Hills they rest directly upon the Permian and at Orleigh Court, on the Culm Measures. This gradual overstepping is known as the ' Cretaceous Overstep.'

(2) GAULT AND GREENSAND

In Devon the lowest member of the Cretaceous series consists of some 20 to 25 ft. of dark blue loamy silt, occasionally conglomeratic at the base, known as the Gault. Fossils are scarce, but a sufficient number has been obtained to show that this Gault is the equivalent of part of the Lower Gault of south and south-east England.

This Lower Gault can be traced along the coast from Lyme Regis to Culverhole, near Seaton. It is probable that west of Seaton the lowest 20 ft. of dark green clayey sand of the Greensand may represent the Lower Gault.

Inland the Gault has been recorded from the railway cutting at the eastern end of the Honiton Tunnel (Southern Railway), north-west of Wilmington. It appears therefore that the Lower Gault does not extend far west of a line drawn north-south through these two points.

Northwards around the Blackdown Hills there is no record of its presence.

Owing to the impervious nature of its beds the Gault throws out water at its junction with the overlying Greensand, and where its outcrop is wide it gives rise to difficult problems of drainage.

Fig. 19.—*Geological sketch-map of the Cretaceous rocks of Devonshire, West Somerset and part of Dorset.*

From the Gault there is a passage into the overlying Greensand. Of the latter a lower series of yellow-green sands (*a*) (Foxmould) with basal sandy concretionary masses (Cowstones), is overlain by yellow-white quartz sands interbedded with layers or nodules of Chert (*b*) (Chert Beds). These in turn are overlain by dark glauconitic sand which becomes increasingly quartzose upwards and passes into an indurated hard nodular rock capping the Greensand, and known as the Calcareous Grit. In the west, however, there is no very distinct line between the upper dark glauconitic sands and the Chert Beds below, nor is the Calcareous Grit clearly differentiated.

The Cowstones and the Foxmould up to the Chert Beds have been assigned to the Upper Gault, whilst the Chert Beds and beds up to the top of the Calcareous Grit belong to the Zone of *Pecten asper* (Upper Greensand, Warminster Beds).

The ' Greensand ' of Devon is therefore the equivalent of the Upper Gault and the Upper Greensand of districts farther east, the change of the Gault from clay to sand occurring in Dorset at White Nothe, near Swanage. Consequently, it seems impossible to separate lithically the Upper Greensand from the Gault through West Dorset and Devon, and the two divisions are mapped as Greensand.

In addition to the westerly overstep of the Cretaceous Series upon progressively older rocks, there is also a westerly overlap of members of the ' Greensand ' formation by higher beds of the same formation.

The Greensand of Devon decreases in thickness from east to west. In East Devon it is 200 ft. thick, at Beer, 156 ft., at Peak Hill, Sidmouth, 90 ft., whilst in the most westerly outliers of the Haldon Hills, near Exeter, the minimum thickness recorded is 75 ft. Inland it is only at those localities where outliers of the Chalk are preserved that the Greensand is complete : elsewhere it is difficult to estimate the thickness of the series because of extensive landslips and the masking of the beds by downwashes of chert and sandy loam. At the Blackdown Hills 100 ft. of Greensand has been recorded ; but this figure is probably too low, and there is no reason to suppose that the total thickness is less than on the coast.

(*a*) FOXMOULD

The Cowstones and the Foxmould sands in the east consist of white or yellowish-green glauconitic sands, relatively unfossiliferous, but at Culverhole, near Seaton, and at Blackdown Hills, the beds mentioned below yield many fossils.

These sands are 170 ft. thick near Lyme Regis but decrease to 90 ft. near Seaton (Pl. IX B).

The Blackdown Hills have long been known to geologists because of the beautifully preserved chalcedonic shells of molluscs found in the Greensand. The chalcedony was derived from waters percolating down from the overlying Chert Beds. The Blackdown Hills were formerly celebrated for their scythe-stones ; these were made from irregular siliceous concretions lying in the Greensand, and obtained by driving tunnels into the hillside. Upon exposure to the air the nodules became hardened to form excellent stone. Among the waste material of these workings many fossils were found and collections of them, such as that of the Rev. W. Downes, which is now in the Exeter Museum, were made.

Some of the commonest fossils are : *Trigonia aliformis*, *Glycymeris umbonatus*, *Protocardia hillana*, *Murex calcar*, *Turritella granulata*, *Aporrhais calcarata*, *Inoceramus concentricus*, *Neithea quadricostata*, *Ostrea diluviana*, *Exogyra conica*, *Cyprina cuneata*, *Grammatodon carinatus* and *Rhynchonella dimidiata*.

(*b*) CHERT BEDS

The Chert Beds consist of yellow-buff siliceous sand locally hardened, interbedded with layers of chert, or lines of chert nodules. The distribution of the chert is irregular, for though it often occurs throughout the group known as the Chert Beds, in many places it is confined to the base and in others to the top of the formation.

The cherts may be black, but are more often dull-grey, pink or pinkish-yellow in colour : it is these cherts that have furnished material for the manufacture of the Palaeolithic implements found in the Axe Valley gravels.

The thickness of the Chert Beds is about 20 ft. ; but it increases westwards to 76 ft. at Hooken Cliff, near Beer. Inland the Chert Beds give rise to many abrupt scarps bounding bold hills, as for example, Honiton Hill and Buckton Hill (Pl. XI A), and in the past they have furnished most of the road metal of the district. West of Chard the beds were much worked at the Snowdon Hill quarries, where they are 30 ft. thick.

It is a notable fact that wherever the Chalk has been removed from the Greensand, the Chert Beds have been rapidly disintegrated by weathering ; the sand has been washed out, and the chert layers have settled down in broken masses, thus giving rise to a considerable thickness of tightly packed angular chert. It is probable, however, that many of the angular chert deposits have not been formed *in situ*, for although weathering originally caused the disintegration of the beds, later the fragments were transported and now form the Angular Chert Drift.

The Chert Beds are well exposed along the coast from Lyme Regis to Culverhole, and can be examined in the fallen masses of the Axmouth Landslip. Farther west the Chert Beds form a fine cliff at Kempstone Rocks, near Dunscombe.

(*c*) GLAUCONITE SANDS AND CALCAREOUS GRIT

Above the Chert Beds lie a few feet of dark green glauconitic sand, locally indurated to form sandstone, which is frequently crowded with *Exogyra conica*. Upwards these sands become increasingly quartzose until they form a coarse quartz sand which in its higher layers has become a massive nodular grit, the Calcareous Grit, a bed that forms prominent features. This grit locally contains many fossils, the commonest being : *Exogyra conica*, *Discoidea subuculus*, *Holaster laevis* and *Pecten asper*.

Between Crewkerne and Chard the grit is well exposed below the Chalk on Windwhistle Hill. West of Chard, on Snowdon Hill, it is 9 ft. thick. Along the coast west of Lyme Regis it can be examined among the fallen blocks of the landslip, where it is fossiliferous but coarser and more nodular than at places farther east.

Near Sidmouth the line of demarcation between the Chert and the overlying beds is not very distinct, but there is a calcareous sandstone 8 to 10 ft. thick that seldom contains chert : this sandstone passes westwards into a calcareous sand, largely composed of broken shells, that may represent the Calcareous Grit of the localities to the east. It is noticeable, however, that the fossil *Pecten asper*, common in the grit of the eastern localities, is not found in the calc-sandstone, but in the basal conglomerate of the Chalk which immediately overlies it. Similar conditions occur at Snowdon Hill, near Chard.

Cretaceous rocks occupy the tops of two hills at Haldon, which rise to heights of about 800 ft. above the sea, and form the most south-westerly Cretaceous outliers in England. The beds consist of sand with irregular seams or nodules of chert and cherty sandstone belonging to the higher zones of the Gault and beds with *Pecten asper*. Above these undisturbed strata occur flint gravels with casts of fossils belonging to various zones of the Chalk up to and including that of Marsupites.

It seems, therefore, that in addition to the Upper Gault and Upper Greensand the Upper Chalk was also present in this area.

The Haldon Beds form a westward continuation of the Blackdown Beds (Fig. 19) which are sandy representatives of the Upper Gault, the Lower Gault having been overlapped. At Great Haldon there is a still further overlap, the lower part of the Blackdown Beds also being absent. Not only is there this overlap westward but the sands have become in places coarse-grained, granitic, or even pebbly. Their fauna is suggestive of shoal water, or even of a shore-line within a few miles. Compound corals resembling littoral forms, absent from Blackdown, are here abundant and varied, and the mollusca are thick-shelled strong species, but there is no direct evidence of the actual proximity of land, for no Cretaceous rocks have been found on the flanks of Dartmoor. The maximum thickness appears to be about 65 ft. The beds are supposed to attain a total thickness of 100 ft. at Little Haldon in a pit at Smallacombe Goyle where the following sequence can be traced :—

	Ft.
Surface soil and flint gravel – – – – – –	– 7 to 9
Sharp coarse yellow sand, with irregular masses of chert up to 2 ft. in diameter in rude layers – – – – – –	30
Brownish sand without chert – – – – – –	15
Coarse brownish greensand, with large grains of glauconite, and lenses of white sand – – – – – – –	7
Green sand with lumps of chert, current-bedded, passing down into glauconitic sand with flattish lumps of glauconitic sandstone – – – – – – – – –	40

About 100

The position of the shell beds and of the coral fauna is probably in the upper part of the lowest 40 ft., where *Exogyra conica* and casts of other fossils were found.

It will be noticed that the thickness of the beds is greater than that of the beds of Great Haldon.

(3) Chalk

In 1826 De la Beche described the Chalk near Lyme Regis and noted the divisions easily to be seen in the cliff face, but our knowledge of the

fossil contents and of the correlation of the beds with those elsewhere is due to the work of C. J. A. Meyer, Charles Barrois, A. J. Jukes-Browne, A. Rowe and C. D. Sherborn. The remarkable variation of thickness of some of the zones and especially of that of *Terebratulina* was ascertained by Rowe and Sherborn.

The Chalk occupies a much smaller area than the Upper Greensand. Inland it caps the high ground to the east and west of Chard, while outliers of it occur near Membury and Chardstock, and at Widworthy and Offwell east of Honiton. Along the coast the Chalk occurs between Lyme Regis and Salcombe Regis, near Sidmouth (Fig. 19).

In the eastern part of the area the upper part of the hard Calcareous Grit at the top of the Upper Greensand has been worn into an irregular erosion surface. Resting upon this surface lies a thin bed of conglomerate which has been considered to represent the base of the Lower Chalk. This conglomerate usually consists of chalk pebbles slightly phosphatized on the surface and of a pale brown colour, mixed up with similarly phosphatized fossils, the whole being set in a buff pasty marl. The conglomerate bed, which varies in thickness from 1 ft. to 3 ft., is immediately succeeded by soft whitish chalk speckled with glauconite which resembles ' Chloritic Marl ' ; it passes upwards into typical soft white Lower Chalk.

Both the conglomerate and the glauconitic chalk are very fossiliferous. At Snowdon Hill, Chard, the glauconitic chalk has yielded *Holaster subglobosus*, *Terebratula biplicata*, *Terebratula semiglobosa*, *Cyprina quadrata*, *Exogyra columba*, *Pecten asper* and *Schloenbachia varians*.

In the conglomerate specimens belonging to the genera *Scaphites* and *Turrilites* are commonly found. Jukes-Browne considered that the conglomerate and the glauconitic chalk are together the condensed equivalent of the Chalk Marl of south and south-east England.

Westwards occur both thinning and overlap of beds, and since the whole of the Lower Chalk becomes a thin gritty conglomeratic limestone, barely 2 ft. thick, neither the basal conglomerate nor the glauconitic chalk can be recognized.

The finest exposures of the Chalk are in the cliff sections between Lyme Regis and Beer.

(a) LOWER CHALK

Besides occurring on the coast from Pinhay, west of Lyme Regis, to Salcombe Regis, the Lower Chalk inland forms the base of outliers near Chard, at Widworthy and Offwell near Honiton, and at Membury and Chardstock.

Between Crewkerne and Chard the Lower Chalk, approximately 90 ft. thick and similar to that developed in Dorset, consists of (3) grey and buff marls, (2) glauconitic chalk passing up into white chalk, (1) the basal phosphatic conglomerate bed.

The Lower Chalk retains these characters as far west as Membury, where it is 50 to 60 ft. thick. Between Membury and Wilmington (4½ miles to the west) and Pinhay (8 miles to the south) a remarkable change takes place. The Lower Chalk (as chalk) disappears and its place is taken by a variable thickness of calcareous sandstone (' grizzle,' not unlike the calcareous grit at the top of the Upper Greensand), which is overlain

(*A*.6381)

A.—BUDLEIGH SALTERTON. THE PEBBLE BEDS.

(*A*.6414)

B.—CLIFF EAST OF SEATON HOLE, SEATON
[For explanation, *see* p. vi.]

(*A*.60)

A.—DOLCOATH MINE, CAMBORNE

(*A*.425)

B.—MULBERRY OPENWORKS, LANIVET
[For explanations, *see* p. vi.]

(*A.*6400)

A.—BUCKTON HILL: CHARACTERISTIC GREENSAND CAPPED HILL
[For explanation, *see* p. vi.]

(*A.*6405)

B.—BEER CHALK QUARRIES
[For explanation, *see* p. vi.]
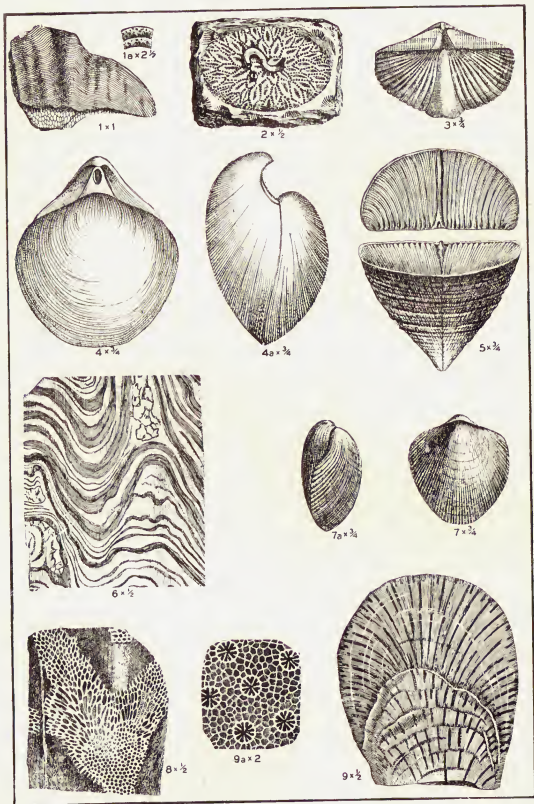
DEVONIAN FOSSILS

Figs. 1–3, Lower Devonian. **1, 1a,** *Pteraspis cornubica* (M'Coy) ; **2,** *Pleurodictyum problematicum* Goldfuss ; **3,** *Spirifer* cf. *subcuspidatus* Schnur. Figs. 4–9 Middle Devonian. **4, 4a,** *Stringocephalus burtini* (Defrance) ; **5,** *Calceola sandalina* Lamarck ; **6,** *Stromatopora concentrica* (Goldfuss); **7, 7a,** *Atrypa reticularis* Linnaeus ; **8,** *Pachypora cervicornis* (de Blainville) ; **9, 9a,** *Heliolites porosus* (Goldfuss).

by a bed of compact quartziferous limestone. On exposure to weather the 'grizzle' locally breaks down into coarse sand, which was formerly dug at Wilmington for rough-casting.

Along the coast from Pinhay westwards the Lower Chalk decreases in thickness to 2 to 3 ft. and varies greatly with overlap of individual beds ; at one locality, between Pinhay and Humble Point, the Lower Chalk is absent and the Middle Chalk rests upon the Upper Greensand.

Near Beer, at Hooken, the glauconitic gritty limestone representative of the Lower Chalk thickens to 30 ft. Westward it thins again to 7 ft. at Branscombe, 4 ft. at Kempstone Rocks, and it is finally seen high up at the eastern end of Higher Dunscombe Cliff.

The following table gives an approximation of the thickness of the several divisions of the Chalk along the coast :—

DIVISIONS	MAIN CHARACTERS	ZONES	Thickness		
			Brans-combe	White Cliff	Pinhay
UPPER CHALK	Chalk with flints and hard siliceous and phosphatic nodules. Chalk Rock at base.	*Micraster cor-testudinarium* *Holaster planus*	Ft. 30 30 60	Ft. 20 + 34	Ft. 50 + 40
MIDDLE CHALK	Chalk with flints. Hard and soft nodular chalk. Beer Freestone developed locally at base.	*Terebratulina lata* *Inoceramus labiatus*	90–156 20– 80	70 28	72 60
LOWER CHALK	Arenaceous chalk frequently rich in quartz grains, glauconitic and conglomeratic.	*Holaster subglobosus* and *Schloenbachia varians*	14– 30	2–3	

(b) MIDDLE CHALK

The Middle Chalk has a very restricted outcrop. Inland it occurs as outliers at Lady's Down between Crewkerne and Chard, at Cricket St. Thomas, Combe St. Nicholas, at Membury and Widworthy and on the cliffs at Pinhay, Whitlands and Beer Head.

As in Dorset, there is no well-defined hard Melbourn Rock at the base : the lowest bed, however, frequently consists of rough gritty limestone containing grains of quartz and glauconite, above which lies a chalk bed full of hard yellow nodules similar to those occurring in the Melbourn Rock.

Where the Middle Chalk enters the area inland, it is probably not more than 80 ft. in thickness. The lower part (*Labiatus* Zone) consists of a loose lumpy chalk passing up into firm white chalk with scattered black flints (*Terebratulina* Zone).

E

At Widworthy the lower part of the Middle Chalk contains a 5 ft. bed of freestone which may be the equivalent of the Beer Stone.

By far the finest exposures of Middle Chalk are seen along the coast in the Ware and Pinhay Cliffs and onwards to the Haven Cliffs beyond Bindon. In the cliff forming the north side of Beer Harbour the finest section of Middle Chalk in Devonshire is seen. The upper 90 ft. belong to the Zone of *Terebratulina lata*, the lower 30 to 40 ft. to the Zone of *Inoceramus labiatus*. It is in the chalk of the latter zone that the Beer Stone occurs, a freestone that has been extensively quarried to the west of Beer (Pl. XI B).

The Beer Freestone yields few fossils, though it is composed almost entirely of coarse shell fragments. The rock is worked by means of adits, and sawn *in situ*, blocks from 6 to 8 tons being obtained. It is soft when quarried but hardens on exposure to the air, and is admirably adapted for carving, especially for interior work. The freestone has a maximum thickness of 13 ft., but appears to be local in its development.

West of Hooken Cliff the upper zone of the Middle Chalk overlaps the lower zone and rests on a thin representative of the Lower Chalk.

Middle Chalk extends west to Branscombe Mouth and is last seen in Higher Dunscombe Cliffs.

(c) UPPER CHALK

The Upper Chalk outcrops only in two small outliers north of Chard, along the coastal hills between Lyme Regis and Rousdon, and at Beer.

The basal Chalk Rock consists of a hard cream-coloured limestone, with inclusions of brown phosphatic material, and reaching 12 ft. in thickness at Pinhay.

The Upper Chalk as a whole is nodular with prominent bands of black flints. The finest section of Upper Chalk occurs at Whitecliff (Annis' Knob) between Seaton and Beer, whilst Beer Head forms the most westerly extension of Upper Chalk in England.

IX. TERTIARY AND PLEISTOCENE*

(1) EOCENE

IT has long been known that the various Eocene beds become coarser and more gravelly as they are followed from Hampshire into Dorset. Two different formations, the Reading Beds and the Lower Bagshot Sands, pass westwards into true subangular river gravels ; but at the most westerly point to which the Reading Beds can be traced the Bagshot gravels had cut through them and rested on the Chalk. The constituents of these gravels prove that farther west rocks older than the Chalk were then exposed including Jurassic, Permian, Palaeozoic, and also a granite.

The gravels that cap the Cretaceous rocks on the Great and the Little Haldon Hills are probably of Bagshot age though there is nothing to prove their exact position in the sequence.

Both of the Haldon Hills are flat-topped and each is capped by a thick sheet of coarse, partially rolled gravel, mixed with seams of granitic sand and whitish clay. The composition is peculiar, for a large part consists of more or less worn masses of Chalk flint, often of large size, though the nearest Chalk outlier lies 15 miles away to the east. The rest of the material consists of subangular Greensand chert and Palaeozoic stones, the latter perhaps more often derived from the Permian breccia than directly from the Palaeozoic rocks. The matrix consists to a great extent of rough granitic sand, mixed with whitish clay derived probably from the decomposed felspar of the granite.

Locally the gravel reaches 30 to 40 ft. in thickness, but it has been thoroughly decalcified and therefore is without fossils except casts in flint of Cretaceous forms.

(2) OLIGOCENE

The clays and lignites of the Bovey Tracey region have long been known and worked. The ‘ Bovey Basin ’ appears to be a deep rock-basin possibly originating in a ‘ rift-valley,’ the middle of which has locally sagged far below the level of the outlet. The thickness of the beds is unknown, but the borehole at Heathfield was 667 ft. deep when work ceased, and it did not reach the base of the Oligocene deposits. Local subsidence of the valley bottom formed this lake-like depression, and the lake was at least ten miles long and about four miles wide. The lake received the drainage of several mountain-torrents from Dartmoor which pushed out extensive deltas of granitic sand and mud mixed with masses of wood and peat that formed lignite. Towards the margin the Bovey Beds become very coarse and gravelly. From top to bottom the lignites contain twigs of *Sequoia couttsiae* in many cases in enormous profusion, and it is probable that the bulk of the peat is formed of this tree, although

* This subject, as regards Cornwall, has been ably summarized, with an up-to-date bibliography, by Mr. J. Robson (1946).

Nyssa and *Cinnamon* are also abundant. These trees formed water-logged rafts of vegetation of the nature of ' pine rafts,' but no suggestion of a swamp deposit has been found ; true swamp vegetation, despite a long search for it, was represented only by a single scale of a cone belonging to the swamp-cypress *Taxodium distichum.* The closest parallel to the beds are the brown coal deposits of Germany which are generally accepted as the highest Oligocene strata, though some consider them as Aquitanian or lowest Miocene.

On the eastern side of the basin the lower part of the Bovey Beds can be studied in numerous exposures, from which the following section can be compiled :—

(1) Sandy beds are prominent in association with clays and a subordinate amount of lignite.

(2) ' Potting Clays ' or ' Whiteware Clays '—used in the manufacture of high-grade white earthenware—with associated lignite clays and lignite seams.

(3) ' Stoneware Clays '—a group of siliceous clays used in the manufacture of coarse ware such as drain-pipes, tiles and bricks ; some local development of sandrock. No lignite beds.

(4) ' Pinks '—siliceous clays with grains of iron oxide. No seams of lignite.

(5) The lowest division of sands and gravels with some clay. No lignite noted.

The most important bed of lignite, known as the ' Big Coal,' locally exceeds 10 ft. in thickness. The lignite has been used as a fuel in the potteries ; it yields up to 4 per cent of montan wax.

Lacustrine deposits, known as the Marland Beds, occur in the neighbourhood of Petrockstow in North Devon. These beds closely resemble the Bovey Beds, but there is no proof that they are of the same geological age. The tract is about $\frac{1}{2}$ to $\frac{3}{4}$ mile broad and $4\frac{1}{2}$ miles long. Its surface rises imperceptibly in level towards its margins. The top soil is stony brown clay 5 to 10 ft. thick containing numerous large boulders, and below it white plastic unctuous clay, stoneware clays and argillaceous sands, with thin carbonaceous layers, up to 80 ft. thick. Irregular layers of lignite from a few inches to a foot thick occur. The beds are worked along drifts driven at different levels from inclined shafts, the principal products being blue ball-clay, pipe clay and stoneware clay from which ' facing ' and acid-proof bricks are manufactured.

(3) High-level Platforms of Unknown Ages

One of these occurs at 1,000 ft., another between 750 to 800 ft. and a third about 430 ft. above sea-level.

The 1,000-ft. platform is best seen around Moreton Hampstead. It may be a general base-level plain of Upper Oligocene date, the great erosion of which, seen in the Bovey river drainage area, may have produced the material which filled up the pre-existing Bovey Basin, at first 1,600 ft. deep ; or the 1,000-ft. platform may represent a base-level plain of much later date—a Miocene feature.

The 750 to 800-ft. platform is conspicuous over much of Dartmoor and is well seen at Lydford where the great gorge has been incised in it. In all probability it belongs to some part of the Miocene period.

(4) Pliocene Platform

The 430-ft. platform has been traced from end to end of Cornwall and in parts of Devon. It forms a strongly marked shelf or plane of marine denudation (Frontispiece) ; its upper boundary is a degraded cliff which may cut obliquely across any geological boundary while rocks of different degrees of hardness are equally levelled. Deposits of Pliocene or late Miocene age occur at St. Erth. At that village, near the bottom of a wide open valley, which existed before the notch was cut, the Pliocene sediments were laid down. The series in descending order is as follows :—

> Vegetable soil
> Head
> Yellow sand
> ' Growder ' (very coarse ferruginous sand)
> Yellow sand
> Blue clay with fossils
> Quartz pebbles
> Fine quartzose sand
> ' Growder '

The fauna contains upwards of 250 species of marine mollusca and nearly as many foraminifera. The percentage of extinct species of mollusca is also large and the Mediterranean affinities most striking. It has been called Newer Pliocene, Older Pliocene and Miocene.

These beds lie at 100 ft. above present sea-level. Although many of the shells probably lived at a depth of about 15 fathoms, littoral shells such as *Patella* and *Littorina* are absent, as are also *Scrobicularia*, *Cardium edule* and *Hydrobia ulvae* which inhabit sheltered creeks and estuaries. Clement Reid (1890) argues that the lithological character of the clay points to deposition in fairly still water at probably not less than 50 fathoms. If this depth is correct the land would then have been 400 ft. lower than to-day, and this figure approximates with the amount of uplift of the plain of erosion.

Around the mining region near Camborne the plain is conspicuous, the ' island ' of Carn Brea rising from it, while the island of St. Agnes Beacon with its base mantled with sand and clay can be seen ' floating ' above the general surface of the north coast of Cornwall, from numerous view points. The clays of this area have long been dug for ' candle clay ', used in the mines for fixing candles at convenient points, and pottery clay for coarse pottery manufacture and brick making. At the base of these beds the old sea-beach is locally exposed, and among pebbles of igneous rocks, vein quartz and sediments, nuggets of tinstone have been found. Conspicuous also is the cliff at Tintagel and Boscastle, while the inland extension of the platform forms the dreary Goss Moors and the land above Luxulyan valley. Elsewhere its sands have been dug, especially at Crousa Downs, near Coverack, and on Polcrebo Downs, near Crowan.

Uplift of this plateau led to rapid overdeepening of the river valleys, and the characteristic steep-sided gorges of Cornwall and Devon resulted

from this incision. St. Nectan's Kieve, the Rocky Valley, Lydford Gorge, and Lustleigh Cleeve are well-known beauty spots due to this agency.

(5) RAISED BEACHES AND BURIED VALLEYS

Elevated strand-lines occur at two levels, one at 65 ft. above sea-level and the other at about 15 ft. Only at Penlee Quarry, near Mousehole, is the higher beach preserved ; the ancient cliff is there seen with coarse beach deposits banked against it.

Where the land slopes gently to the sea the lower shelf widens out into a broad platform with a small bluff at about 15 to 20 ft. above mean tide level, marking the ancient cliff. At numerous localities the old beach is preserved. A general sequence of deposits in descending order is as follows :—

> Blown sand
> Boulder bed = boulder clay in North Devon and South Wales
> Head
> Current-bedded sand with a temperate fauna
> Boulders and gravel
> Raised beach platform

On the raised beach platform of North Devon large erratics of rocks alien to the district and probably derived from Western Scotland lie among the beach deposits. They were probably carried by floating ice, and therefore belong to a cold period. The raised beach boulders may be related to striated erratics, some apparently derived from Scotland, that occur with beds of clay at Fremington, south-west of Barnstaple. There are three small areas of clay underlain by gravel. The clay, which has a maximum thickness of 78 ft., is tough, homogeneous and free from grit and it may be a true boulder clay. It is dug for pottery-making. The beach deposits are succeeded by current-bedded cemented sands with a temperate fauna. These are finely exposed in Fistral Bay, Newquay, where some notable cylindrical hollows called Piscie's Caves occur. Next above these sands masses of unassorted detritus have channelled the sands and consist of the so-called ' head ' which was formed under glacial or sub-glacial conditions. Above this detritus lies the boulder bed which is best exposed at Trebetheric Point near Rock, and is correlated with the boulder clay of South Wales and South Ireland.

Subsequent elevation led to renewed overdeepening, and submerged valleys infilled with alluvium up to 120 ft. in thickness occur in the estuaries. The upper parts of these submerged valleys reveal at low tide the buried forests. The infilled buried valleys occur alike on the south and north of the peninsula and have occasioned much trouble and expense to engineers. The deposits were formerly in great part removed in the search for stream tin in Southern Cornwall, and remains of deer were of common occurrence. The drowned valleys of Cornwall and Devon are of the ' Ria ' type and do not resemble fjords. The Tamar at Plymouth, the Fal estuary and the Camel at Padstow are typical examples of rias.

(6) Caves and River Deposits

Several caves in South Devon have become classic on account of the remains of extinct animals in association with Palaeolithic implements of several types and ages that have been found in them. The principal cave is Kent's Cavern, which lies in the Wellswood district on the west side of a valley leading to Meadfoot Sands (near Torquay). There are two entrances to it both lying at 180 to 190 ft. above mean tide-level and 60 to 70 ft. above the bottom of the valley and three other entrances, now blocked by talus, 20 ft. lower down the hillside.

McEnery's[1] researches in the years 1825 to 1829 established the occurrence of flints worked by man among bones of extinct mammals, a discovery which led to much controversy and to the systematic exploration of the cavern by the British Association in the years 1864 to 1880. In recent times investigations have been carried out by the Torquay Natural History Society. The materials infilling the cave are indicated in Fig. 20. The Black Mould, an important deposit, formed the top layer : in it were found antiquities ranging in age from Neolithic to Mediaeval, associated with bones of domestic animals and of seal, fox, badger, brown bear and long-horned ox.

The Granular Stalagmite had a maximum thickness of about 3 ft. : it originally extended nearly all over the cavern but was absent from the extreme western parts and from the large chamber opposite the southern entrance. Embedded in it are bones of brown bear, mammoth, hyaena, woolly rhinoceros, horse, fox and man, and a few flint flakes and cores too indefinite for classification.

The Black Band comprised the highest part of the Cave-earth, and was so called on account of its dark colour which was due to the presence of burnt bones and charcoal. It was of only local occurrence and probably represented a series of hearths, but it is of archaeological importance because of the artifacts found in it. These included a bone needle and an awl, uniserial and biserial horn harpoons, end-, hollow- and keeled-scrapers, and gravers and points with battered backs and some with a tendency to geometric forms.

The Cave-earth though unstratified shows by the rolled condition of the bones which it contains that it was once washed by water. It is mainly a reddish loam containing angular lumps of limestone and some of grit : occasionally blocks of the underlying Breccia and Crystalline Stalagmite are met with. It covers much of the cave floor and occupies fissures and hollows, in one spot to a depth of 23 ft., but in parts of the south-western galleries it dies out.

A great number of bones and teeth of extinct animals gnawed by hyaena are mixed with the Cave-earth and it is probable that the cave was of the nature of a hyaena-den. In addition to abundant remains of hyaena, those of horse, woolly rhinoceros, cave lion, cave bear, grizzly bear, reindeer, stag and bison were also common ; rather rare were bones of mammoth, wolf, brown bear and beaver. Many other species were found, including glutton, cave pika and sabre-toothed tiger.

The Crystalline Stalagmite is harder and denser than the granular

[1] *Trans. Devon Assoc.*, vol. iii, 1869, p. 191.

floor and locally it attains a thickness of 12 ft., but it dies out altogether in parts of the cave.

The Breccia consists of rounded, subangular and angular pieces of red grit in a sandy matrix, with some fragments of limestone and up to 50 per cent of bones and teeth, principally of bear, cemented into a hard rock. Rolled implements of Chelles type have been found at all levels in the breccia, but they were not numerous.

The fauna of the Cave-earth is late Pleistocene and the implements recovered represent four periods at least. This mixture of types is probably due, however, to the manner in which the samples were collected,

Limestone roof — — — —
    with swallow holes
Cavern space — — — — —
Black Mould — — — — —
Granular Stalagmite — — —
Black Band — — — — —
Cave-Earth — — — — —

Crystalline Stalagmite

Breccia — — — — — —

Irregular Limestone floor
    with hollows and fissures

Vertical Scale 0   5   10 FEET
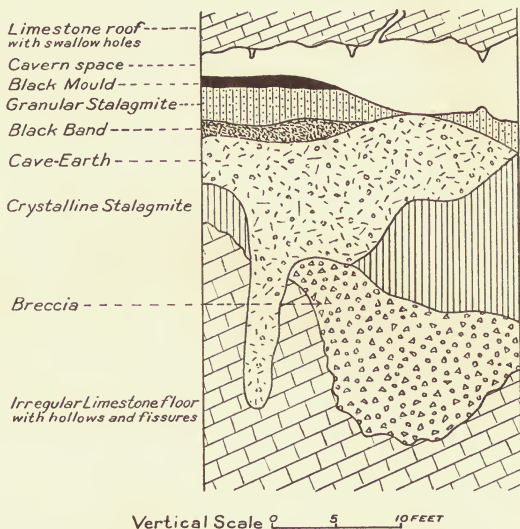
Fig. 20.—*Diagrammatic section of deposits in Kent's Cavern.*

i.e. in foot-levels which do not correspond with the stratification. Pengelley, however, left in his journals the exact location of all the finds and from his notes and the implements Miss Garrod was able to attempt a correlation of the artifacts. The oldest series is the Mousterian, which includes a number of heart-shaped hand-axes and some well-made sidescrapers and large rough flakes all of chert.

The next group consists of scrapers of Middle Aurignacian types similar to those from Paviland, a bone pin, and some flint and chert flakes. The third group includes points comparable with proto-Solutrian types, but not many flakes or cores were found.

The fourth group contains the largest number of implements and flakes and belongs to the end of Palaeolithic times.

The majority of the implements come from the Black Band, a series of hearths, which lay immediately beneath the upper stalagmite floor. They can be dated by their association with a reindeer-antler harpoon that has a single row of barbs and one with two rows of barbs, and some needles of bone. The industry as a whole has none of the characters of the classic Magdalenian, for gravers are very rare and the leading form is the *dos rabattu* point, but the bone and antler implements are typically Magdalenian.

A full history of the explorations of Kent's Cavern has been given by A. S. Kennard (1945).

Other caves in the limestone have yielded flakes and bones.

No Palaeolithic implements have been recorded from the river deposits of Cornwall and West Devon although in East Devon they occur in great profusion in the gravels of the river Axe, at Broom, near Axminster. These gravels consist chiefly of Greensand chert, flint and quartz ; blocks of schorl-rock are also met with. They have long been worked either for ballasting the track of the railway or for the roads. They occur in the form of flattened deltas up to a known thickness of 45 ft. without reaching the base. The gravel below that depth is flooded and appears to extend below the level of the river. There appear to be two implementiferous levels, one yielding pointed hand-axes and the other ovate and cordate forms, and large flakes. Many of the implements are large and beautifully trimmed and some of the ovate hand-axes show the reversed S twist on their edges. They may be assigned to a late Acheulian period in form and technique. In the gravel of Kilmington, which extends to a depth of 80 ft., rudely chipped cherts have been found.

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